Chapin

TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XIX.

JULY TO DECEMBER, 1888.

NEW YORK:
PUBLISHED BY THE SOCIETY.

1888.

TRANSPORTATION LIBRARY

Transportation
Library
TA
1
.A526

OFFICERS FOR THE YEAR ENDING DECEMBER 31, 1888.

THOMAS C. KEEFER, *President.*

J. JAMES R. CROES, ROBERT MOORE, *Vice-Presidents.*

JOHN BOGART, *Secretary and Librarian.*

GEORGE S. GREENE, JR., *Treasurer.*

MENDES COHEN, JOSEPH M. WILSON, STEVENSON TOWLE,
CHARLES B. BRUSH, ALPHONSE FTELEY, *Directors.*

Entered according to Act of Congress, by the AMERICAN SOCIETY OF CIVIL ENGINEERS, in the office of the Librarian of Congress at Washington.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

393.
(Vol. XIX.—July, 1888.)

PRELIMINARY REPORT OF THE COMMITTEE ON THE PROPER RELATION TO EACH OTHER OF THE SECTIONS OF RAILWAY WHEELS AND RAILS.

To the President and Members of the American Society of Civil Engineers:

Your Committee to whom was referred the question raised in the subjoined resolution* have been greatly impeded by pressure of other duties from holding such meetings and giving the matter such study as would warrant the submission of a final report in the first instance,

* The Committee is acting under the following resolution:

"*Whereas*, The relation which the form of the head of a rail should bear to the section of a car-wheel tread and flange has recently been in dispute, it being asserted on the one hand, that they should have as long a line of contact as possible, and, on the other hand, that such long contact would be dangerous and injurious; and,

Whereas, The question raised by this diversity of view is of direct importance to the many members of this Society, as well as to the public interest, and hence is one which this Society may appropriately consider through Committee; therefore be it

Resolved, That a Committee of five members of this Society be appointed by the President to consider and report to the Society on the proper relation to each other of the sections of rails and wheels; to what extent and at what points it is expedient that their sections should be such as to bring them normally in contact, and to what extent and at what points it is not expedient that they should be so in contact; and that the Committee be instructed to seek information from all those who are known to have given the subject attention."

This resolution was submitted to letter ballot and adopted by a general vote of the Society. Subsequently, by vote at the annual meeting, the President was authorized to add two additional members to such Committee.

and in view of the importance of the question raised it seems undesirable to do so in any case until the information which they have collected and the conclusions which seem to be indicated have been submitted for discussion, with the probable result of bringing out further information bearing on the matter. They therefore submit the following preliminary or progress report, postponing to a later date the preparation of a final report giving conclusions.

Your Committee understand the question submitted to them to be in substance this: Is it preferable that the sections of rail and wheel should stand to each other in the relation shown in Fig. 1, in which the fillet of the flange is to a larger radius than the corner of the rail, so that the rail and wheel can only come in contact on the top or at a single point on the corner, or is it desirable that the radii of the flange-fillet and rail corner should be the same, as also the radii of the inside half of the rail-top and the corresponding part of the wheel-tread, so that the two shall be normally in contact with each other over the entire distance from *A* to *B*, both on curves and tangents, as shown in Fig. 2, whenever the flange approximates to the wheel at all.

The Claims Made on Each Side.

Summarizing these as impartially as may be, it is claimed in behalf of the form shown in Fig. 1:

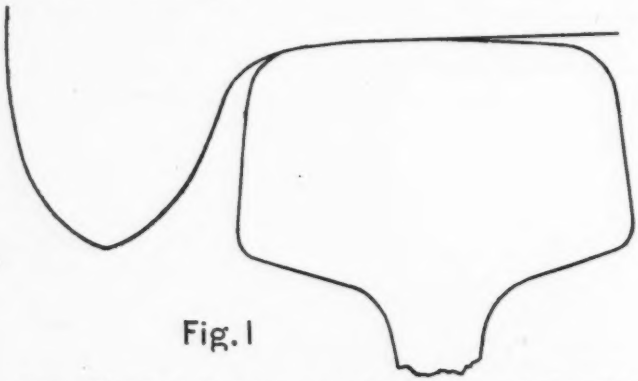


Fig. 1

First.—That it is the customary and most common form, and has the burden of proof in its favor, being now almost universal.

Second.—That it is the most practically convenient and attainable

form, since it does not require the radii of either fillet or rail corner to be always the same, whereas the conditions of Fig. 2 are only attainable by universal agreement to make both rails and wheel always of the same radii.

Third.—That it is the form of least wear, since on tangents and on the inside rail of curves there is a purely rolling contact on top, and on curves an almost purely rolling contact on the corner of the rail, whereas in Fig 2 there is rubbing flange friction at *A* both on curves and tangents, which produces an excessive wear from the beginning of the life of the rail, such as can only exist in Fig. 1 on old outside rails of curves after they have been much flange worn, as in Fig. 2 below.

Fourth.—That it is the safer form, in that the flange will not so readily mount the rail.

Fifth.—That the form of the rail is not as a matter of fact a cause for sharp flanges to any appreciable extent.

Sixth.—That even if it were, the loss by sharp flanges is a small one, if indeed there be any.

On behalf of the form shown in Fig. 2 it is claimed:

First.—That the form shown in Fig. 1 offers too little bearing surface, which it is desirable to increase.

Second.—That the form shown in Fig. 1 is a cause for sharp flanges, which is removed by making the fillet and rail corner exactly fit each other, as in Fig. 2.

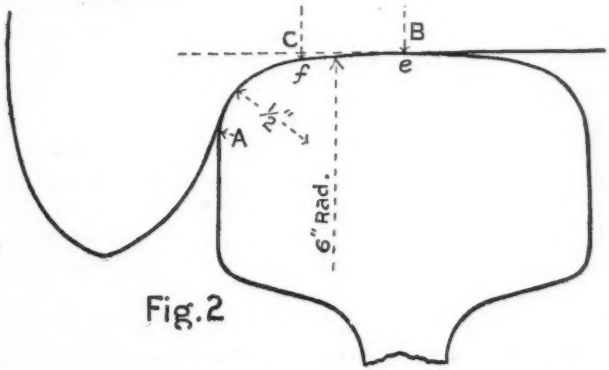


Fig. 2

Third.—That the loss from sharp flanges is so serious as to demand a remedy.

Fourth.—That no extra wear or extra danger of derailment will result from the form shown in Fig. 2 to outweigh its alleged advantages.

Your Committee have collected quite a body of statistical information relating to the question submitted, much more, they apprehend, than has ever been collected in relation to the question before, including some of a quite novel character specially compiled for them, which sheds a great deal of light on it. This is especially true of the records of the Pennsylvania Railroad, which from the many years (ten) and vast number of wheels which they cover, are of quite unequalled value for the purpose in view. Their completeness has also enabled your Committee to trace to its source an error of great magnitude and importance in regard to the proportion of sharp flanges on the Pennsylvania and other roads, which appears to have had a good deal of influence in creating the antagonism of views which led to the appointment of your Committee.

They have subdivided their investigation, and the following report, under the following heads: First, Historical; second, Statistical; third, Theoretical; fourth (to be given in a final report), Summary of conclusions.

History of Action on this Question.

Your Committee have not been able to discover that the doctrine that the rail and fillet radius should correspond has ever been advanced in any authoritative way until within the past few years. The first formal action to that effect was a brief report by a Committee of the Master Car Builders' Association in 1883, who stated that they were "strongly of opinion that by far the greatest cause of sharp flanges" was the sharp corners of the rails, and recommended that the rail be rounded off to a $\frac{5}{8}$-inch radius, so as to "exactly fit the flange." The conclusions of a previous Committee, that sharp flanges were due to special defects of truck and wheels, bad gauge of wheels, trucks not square, wheels not of the same diameter, overloading of side bearings, unequal loading of car, imperfect chilling, etc., were enumerated as secondary causes.

No action beyond receiving it was had on this report, but immediately thereafter Mr. M. N. Forney, M. Am. Soc. C. E., Secretary of the Association, took up the matter in an elaborate paper presented at the 1884 Convention, information for which was gathered by circular in

the name of the Association and which was (in effect) endorsed and accepted by the above-mentioned Committee as giving their views and relieving them of the necessity of making a report.

This paper has been very widely circulated. Officers of Maintenance of Way were formally invited to attend and take part in its discussion, and your Committee have reason to believe that this paper and resulting action thereon has largely given rise to the unfounded impression, which is nevertheless widespread, that the Master Car Builders' Association, as a body, has acted on this matter, and that the paper was *a quasi* official protest on their part against the bad form of rails. This is not the case.

At about the date of this paper the Pennsylvania Railroad changed their standard to a round cornered rail, and one or two other roads followed suit. Several years previously, in 1883, the Lehigh Valley Railroad adopted what is now their standard section, and generally known as the Sayre rail, designed by Mr. Robert H. Sayre, C. E. In regard to his reasons therefor he states in a letter to a member of your Committee:

"The sharp cornered rail attacks the wheel in its most valuable point, and while the rail is being worn down to conform to the normal shape of the wheel, you are ruining the wheel, which costs more per ton than the rail, by cutting through the chill and wearing the flange straight. Carefully kept records on the Pennsylvania Railroad for a period of five years, while they used a sharp cornered rail section, showed that 40 per cent of their wheels removed were worn through the chill in throat or had straight flanges. I had records kept on the Lehigh Valley Railroad for three years, and found the loss from the same cause was less than 4 per cent."

Passing for the present the questions raised in the first part of this quotation,* the substance of the closing sentence has been repeatedly alleged by various persons in the discussions of the Master Car Build-

* It may perhaps be well that your Committee should here note, however, that the first sentence above, in respect to "the rail being worn down to conform to the normal shape of the wheel" does not seem to conform to the facts of experience, as evidenced by the accompanying sections of worn rails (Figs. 32 and 33), reproduced from Mr. Forney's paper, before referred to. Fig. 32 is from a rail laid on tangent on the Philadelphia and Reading Railroad in 1875, and taken up in 1882, after about 105,000,000 tons had passed over it. Fig. 33 is from a similar rail laid in 1867, after 176,000,000 tons had passed over it. In both cases it will be seen that the original round corner has worn down to a very sharp corner. It is obvious that if it be in fact the case that the rail corner tends to cause sharp flanges by wearing away the fillet to a smaller radius, the tendency of the flange fillet should be to wear off the rail corner to a larger radius; yet the two rails shown, made with the original corner-radius nearly as large as the flange fillets, for the express purpose of avoiding wear in the latter, have worn down to about as small corner radii as are ever used in new rail sections.

ers' Association and elsewhere, and your Committee think there is reason to believe that this one supposed contrast in statistics has had very great influence with many persons and on much of the action had, in favor of round-cornered rails to fit the flange. They have therefore investigated its truth with all possible care, and find that it is founded on an entire misapprehension, the error being that the per cent. of worn-out rails only on the Pennsylvania is compared with the per cent. of all wheels on the Lehigh Valley. The correct figures, which appear in this report, and which have never been in print or even collected in manuscript before, indicate that the Lehigh Valley percentage is not now and

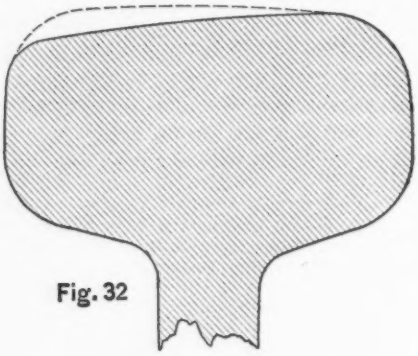


Fig. 32

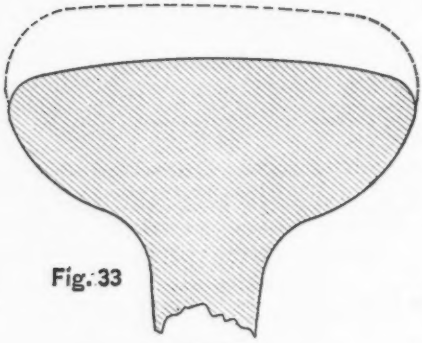


Fig. 33

(Full Size.)

Worn rails, Philadelphia and Reading Railroad, showing tendency of round-cornered rails to wear sharper.

has never been lower than on the Pennsylvania, and (apparently) that on both roads the percentage of sharp flanges has increased very materially since the adoption of the round-cornered sections.

The paper by Mr. M. N. Forney, before referred to, while quite elaborate in other ways, bases the conclusion that the radii of rail and fillet should correspond on the following argument only :

"As the maximum weight carried by car-wheels is now from 5 000 to 8 000 pounds, the bearing surface must be subjected to pressures of from 40 000 to 64 000 pounds per square inch. It is therefore not surprising that they are rapidly worn away, as there is no principle in mechanics more firmly established or more certain than that the wear of surfaces in frictional or rolling contact is in an inverse proportion to their area. Therefore, if we should increase the area of the surfaces of the wheel and the rail which are in contact, the capacity of both for resisting wear will be increased. To do this their forms must be made to correspond to each other. In other words, the treads and flanges of wheels should be made of the same shape as the heads of the rails."

Postponing for the present further discussion of this argument than to say, first, that it neglects the question of whether the recommended course will not substitute mixed rolling and sliding friction for purely rolling contact, and so materially change the nature of the problem, and second, whether the pressures named are really injurious for the bearing surfaces of wheels and spheres, because they are undoubtedly so for the bearing surfaces of prisms, which have no greater section anywhere than their bearing surface, your Committee present it in full, as the only scientific argument which has ever been made public, to their knowledge, in favor of a doctrine which has obtained such wide currency as to be acted on practically by several of our leading lines. Your Committee now proceed to summarize the statistical facts which they have collected in regard to the wear of rails and wheels as affected by their forms.

STATISTICAL RECORDS.—THE PERCENTAGE ON SHARP FLANGED WHEELS.

On this question, as also on the far more directly important question of comparative mileage life, your Committee have collected the information, which appears in the accompanying tables and subjoined appendices, being as much as seemed at all necessary for the purpose.

The relative percentage of sharp flanged wheels needs to be considered in connection with statistics of comparative mileage, to be shortly presented, and it is also to be remembered and allowed for that there is much irregularity in classification. This is especially conspicuous in steel-tired wheels. Thus, the Boston and Albany and Lake Shore and Michigan Southern report no sharp flanges whatever among steel-tired wheels. On the other hand, the Chicago, Burlington and Quincy reports 47 to 50 per cent., although the mileage of these sharp-flanged wheels is higher than any other.

The total per cent. of sharp flanges reported, out of wheels removed for all causes, may be said to range from 2 to 12 per cent. in passenger service, and from 3 to 20 per cent. in freight and engine service. The following are a few definite figures :

TABLE No. 1.

SUMMARY OF THE PERCENTAGE OF SHARP-FLANGED WHEELS IN THE TOTAL REMOVED ON VARIOUS RAILROADS.

ROAD.	Year.	Per Cent. Sharp Flange Wheels.	
		Passenger.	Freight.
Boston and Albany	1884	none.	2.97
Lake Shore and M. S	1886	12.2	no record.
" (steel tired wheels)	1886	none.	.....
Chicago, Burlington and Quincy	1885	6.4	21.5
" "	1886	10.8	20.4
" (steel tired wheels)	1885	47.3	.. ..
" "	1886	50.4	.....
New York, Lake Erie and Western	1884	....	5.8
Pennsylvania	1883	4.45	.....
Pennsylvania Company	1885–86	2.75*	5.0*
Lehigh Valley	1886	....	8.8

Many of the irregularities of this table, as notably for the Chicago, Burlington and Quincy, are due to peculiarities of classification, but further precision or a more elaborate summary appears unnecessary in view of the following facts as to relative mileage life.

* Estimated, by taking one-fourth of the per cent. of worn out wheels only, which is about the ratio of the Pennsylvania returns, which give both percentages.

The Relative Mileage Life of Sharp-Flanged Wheels.

Your Committee find it clearly indicated from all the data which they have collected, and in part append to this report, that the average mileage life of wheels removed for sharp flanges is very decidedly above the average life of all wheels, and is even, with one partial exception, the highest among the various causes for removal of wheels worn out by legitimate wear only. This is assuming the quality of the wheels to be of fair to good quality. As the quality of the wheel falls below this average quality (which includes, perhaps, three-quarters or seven-eighths of all the cast wheels in the United States), the statistics to be shortly presented will show that the percentage of sharp flanges very rapidly increases, and it may well be (although your Committee have no evidence of that fact) that the relative mileage life of sharp flange wheels is less, since bad wheels are particularly apt to be soft in the fillet chill.

The most valuable and decisive evidence as to relative mileage life are the returns of the Pennsylvania Railroad, shown in Table No. 3, and others, since they cover a long period of time (1878–87, ten years) and a large number of wheels, during which time a rigid, minute and uniform system of classification has obtained. The main part of this record covers only wheels which have failed by wear from legitimate causes, excluding all "slid flat" wheels (which covers from 50 to 60 per cent. of all removals under the rigid Pennsylvania inspection), as also all wheels removed for any cause fit for refitting or freight (20 to 25 per cent. of all removals), and also wheels removed as cracked or broken (less than 1 per cent. of the total). The average mileage of these excluded wheels is, of course, vastly lower than those which are included, which fail from wear.

Those which fail by legitimate wear only, are sub-classified under these eight heads: 1, "Shelled out;" 2, "Comby;" 3, "Seams;" and 4, "Worn flat;" terms which in a measure explain themselves, and imply more or less imperfection in the wheel; 5, "Worn flange," under which head are included all wheels ordinarily classed as sharp flanged; 6, "Hollow at flange," wheels worn in tread close to the flange, but not so as to cut into the flange abnormally; 7, "Hollow from flange," which means wheels worn deepest in the tread away from the flange, and presumably mated with wheels which run to flange. To these is added a very small class of miscellaneous.

The comparative service which wheels removed for each of these defects have rendered on the Pennsylvania Railroad for the past ten years is given in detail in the Appendix, and summarized in the following Table No. 2, the significance and importance of which, as respects the question now under discussion, your Committee think it would be difficult to exaggerate. They are not aware that any similar statistics have ever been computed or made public before.

TABLE No. 2.

RELATIVE MILEAGE LIFE of Worn out Wheels only (excluding Slid-Flat and Cracked and Broken Wheels) on the Pennsylvania Railroad. Average of Nine years, 1878–86, as shown in detail in Table No. 3. (1887 added separately for comparison.)

CAUSES OF REMOVAL. (In inverse order of mileage.)	AVERAGE MILEAGE, 1878–86.			
	Baggage, Express and Postal.		Passenger, Combination and Emigrant.	
	1878–86.	1887.	1878–86.	1887.
1. Comby	62 120	70 369	53 840	60 924
2. Seams	64 880	88 974	52 150	62 916
3. Shelled out	71 290	75 483	54 980	58 237
4. Worn (not slid) flat	73 110	78 368	61 310	56 510
5. Hollow in tread at flange	75 550	59 866	63 810	37 516
6. Worn (sharp) flange	78 720	75 390	66 790	60 919
7. Hollow in tread from flange	81 810	70 866	67 450	50 504
Average of the two classes of wheels which fail from wear of tread only and not of flange (Nos. 5 and 7)	78 680	65 366	65 630	44 010
Against sharp flange wheels	78 720	75 390	66 790	60 919
Average of causes 1 to 4	67 850	78 298	55 652	59 647

TABLE No. 3.

SHOWING IN DETAIL THE AVERAGE MILEAGE of Wheels Removed as Worn Out, for each Leading Cause of Removal. Pennsylvania Railroad, 1878–86, inclusive. Wheels Removed as Cracked, Broken or Flat from sliding excluded.

ABSTRACTED FROM THE FULLER DETAILS OF TABLE A, APPENDIX.

1 = 1 000 miles.

BAGGAGE, EXPRESS AND POSTAL CARS.

	Shelled Out.	Comby.	Seams.	Worn Flat.	Worn Flange.	Hollow at Flange.	Hollow from Flange.
1878	88.64	73.20	88.70	77.13	83.05	74.05	91.13
1879	64.24	47.59	75.80	80.97	90.28	81.09	95.43
1880	74.65	53.59	69.35	86.75	85.51	79.78	93.32
1881	68.51	46.89	31.69	60.69	76.17	95.31	80.99
1882	63.98	61.01	48.70	66.13	74.84	70.42	71.35
1883	63.19	64.17	51.70	72.07	71.70	68.53	70.80
1884	65.59	68.22	68.57	62.53	78.06	58.85	75.43
1885	76.12	71.72	67.86	73.73	73.27	79.90	82.85
1886	76.73	72.64	81.59	77.98	75.37	72.06	75.01
Average.....	71.29	62.12	64.88	73.11	78.72	75.55	81.81

PASSENGER, COMBINATION AND EMIGRANT CARS.

1878	65.87	50 91	52.82	64.60	72.18	71.22	82.20
1879	61.29	46.63	87.39	69.25	79.85	77.32	81.38
1880	60 62	53 31	52.61	75.96	76.97	82.23	79.67
1881	59.02	44.61	23.20	57.14	62.51	76.02	71.00
1882	51.99	54.12	37.87	57.78	69.32	64.59	68.37
1883	45.67	54.36	44.56	52.24	67.72	49.90	58.43
1884	44.45	60.11	57.33	58.58	60.33	51.27	55.15
1885	50.49	58.75	56.72	56.28	56.70	54.77	57.29
1886	55.39	61.74	56.88	59.96	55.53	46.94	53.57
Average.....	54.98	53.84	52.15	61.31	66.79	63.81	67.45

This table shows only the nearest even ten miles, because the average was so computed to save space and time.

It will be seen that the average mileage of wheels with "worn flange" is very markedly above the average of other wheels which fail from wear, and is even appreciably higher than the average of the two select classes of choice wheels which fail from "old age" only, *i. e.*, those which show no other sign of defect up to their date of removal than that the tread is too deeply worn (although evenly worn all around) to permit of longer service. This class of wheels constitute only a very small percentage of the total drawn from service (2½ to 3 per cent.), just as old age constitutes a very rare cause of death among human beings, and for precisely the same reasons. It requires an entire absence of specific defects of structure.

An alleged disease among human beings which showed a somewhat higher average age at death than the average of deaths from old age, would not ordinarily be regarded as a very serious matter, nor would there be any great anxiety to decrease the number of those who died by it; and your committee cannot but regard it as a highly significant and important fact that in this most complete record available (which agrees in substance with all the others subjoined), the wheels which show the very highest mileage, practically, are those which have been drawn at last because they were suffering from a disease which it has been supposed was so important to cure, "worn flange."

This is especially notable, if we consider further that (1) there is much less metal to wear away to make a wheel sharp-flanged than to make it hollow-tread; (2) that a hollow-tread wheel has a much greater bearing surface than one which is running to flange, which should reduce the rate of abrasion if the greater bearing surface is a gain, and (3) and chiefly, that inspection will naturally be much sharper and removal quicker with sharp-flanged than with worn tread wheels, the latter being in no sense a dangerous defect.

The following Table No. 4, shows the percentage of the various causes of removal among worn out wheels only, from which it will be seen that the worn flanges are now 37 per cent. of such wheels, and the worn treads, including "worn flat," 13 per cent. The steady increase in number of sharp flanges is notable.

TABLE No. 4.

PERCENTAGE OF VARIOUS DEFECTS in wheels removed as worn out (excluding "slid flat" and "cracked and broken" wheels) from Passenger, Combination, Emigrant, Baggage, Express and Postal Cars, Pennsylvania Railroad.

FOR DETAILS, SEE TABLE A, APPENDIX.

CAUSES OF REMOVAL. (Worn Out Wheels only).	Per Cent. of Each.			Average Mileage Passenger, Combination and Emigrant.
	1878-83, Six years.	1884-86, Three years	1887, One year.	1878-86.
Shelled out	29.83	17.96	13.15	54 980
Comby	7.48	33.88	36.09	53 840
Seams	5.28	1.92	0.89	52 150
Worn flat	10.36	3.90	2.26	61 310
Worn flange	26.63	29.87	36.72	66 790
Hollow in tread at flange	4.84	2.73	1.87	63 810
Hollow from flange	11.90	9.08	8.42	67 450
Miscellaneous	3.68	0.66	0.60	.....
Total (worn out only)	100.00	100.00	100.00	.....

NOTE.—The round-cornered rail ($\frac{5}{8}$-inch radius) was made standard on the Pennsylvania in 1884, and in 1884 a change of fillet radius was made from $\frac{3}{4}$ to $\frac{5}{8}$-inch.

Of the wheels excluded from this table, "slid flat" wheels constituted (probably under a very rigorous classification) from 50 to 60 per cent. of the total removals; "cracked and broken," only a very small per cent.; considerably under one per cent.. Wheels fit for freight service are also excluded, and constitute 20 to 25 per cent. of the total removals.

The more important further evidence as to relative mileage life collected by your Committee, may be summarized as follows:

Pennsylvania Company, 1885–86—passenger wheels, 77 809 miles for sharp flanges, against 81 460 miles average of worn out wheels only. Freight wheels, 79.1 months against 90.5 months. Engine wheels, 83 296 against 83 983 average; all of worn out wheels only.

Lake Shore and Michigan Southern, 1886—Passenger, locomotive and tender cast wheels, 53 572 miles for sharp flanges, against 56 585 for other causes.

Chicago, Burlington and Quincy—

		Mileage.		Percentage Excess.
		Sharp flange.	Others.	Sharp flange.
Steel tired wheels, 33 inches....	1885	43 832	33 615	30.4
	1886	64 393	57 570	11.84
" " all sizes.....	1885	89 241	85 704	4.13
	1886	82 363	90 109	— 8.60
Cast passenger wheels, 33 inches.	1885	43 534	27 099	60.5
	1886	38 565	34 931	10.4
		Life in Months.		
Cast freight wheels, 33 inches..	1885	63	59	6.8
	1886	64	62	3.3

As further evidence, in the Master Car Builders' Report for 1881 a list of forty-two single wheels is given for another purpose, eight of which had sharp flanges, but the mileage of the sharp flanged wheels was considerably higher than the average of those removed for any other cause, even the general one, "worn out."

Your committee know of no evidence of a contrary character to the above to indicate that flange-cut wheels ever show a low mileage. On the contrary, it appears to be a fact well known to those who have given attention to the matter (although it does not seem always to have been duly considered), that sharp-flanged wheels make a very high mileage.

Mr. T. N. Ely, M. Am. Soc. C. E., General Superintendent of motive power of the Pennsylvania Railroad, says in a letter subjoined:

"The average mileage of wheels removed for all causes shows that there is no great difference between those removed for worn tread (or 'hollow from flange') and those removed on account of 'worn flange.'"

"In the majority of cases, however, these worn 'hollow from flange' give the higher mileage, although in some years the reverse was the case."

"In all cases, however, the average mileage of wheels, with these two defects, was much higher than for the other causes."

These notes appear to be based merely on comparison of the nine years separately. When averaged together, as Tables Nos. 2, 3 and 4 above, they give the still clearer and more emphatic evidence shown.

We abstract in Table No. 5 the percentages for each year of sharp flanged wheels (in the worn-out wheels only) on the Pennsylvania Railroad, which shows still more clearly that the percentage of sharp flanged wheels has been increasing since the round-cornered standard rail-sections of 1884 and 1885 were adopted, although that section was adopted with the express purpose of decreasing flange wear.

TABLE No. 5.

PERCENTAGES OF WORN OUT WHEELS only (Excluding Cracked and Broken and Slid Flat Wheels) Removed on the Pennsylvania Railroad, 1878 to 1887, for Worn or Hollow Flanges. [Altoona Cast Wheels, of substantially same composition and quality throughout the period covered.]

CLASS OF SERVICE.	1878.	1879.	1880.	1881.	1882.	1883.	Average.
Baggage, Express and Postal..	29.20	24.14	35.19	30.98	16.28	17.23	25.50
Passenger, Combined and Emigrant.....	28.57	25.45	27.84	34.03	27.95	22.08	27.75

CLASS OF SERVICE.	1884.	1885.	1886.	1887.	Average.
Baggage, Express and Postal.....	23.74	31.67	39.65	39.76	33.70
Passenger, Combined and Emigrant.....	22.32	28 05	33.79	33.69	29.46

In view of all the preceding, your Committee see no escape from the conclusion that in spite of the less bearing surface, the less material to wear away to condemn, and the closer inspection, wheels which are wearing sharp at flange make, if anything, a larger mileage than any other class of wheels, and certainly show no appreciably less mileage under normal conditions. This rather surprising conclusion, which was unexpected to every member of your committee, necessarily implies that the rate of abrasion of metal from wheels which are wearing sharp at flange must be materially less in pounds per thousand miles than in wheels which are wearing hollow in tread, because there is a smaller amount of metal to wear away to have the wheels unserviceable. We shall shortly see reasons why this should be so, both from theory and from observations on rail-wear, but before doing so it will be desirable to summarize the evidence of statistics as to the causes of sharp flanges.

The Causes of Sharp Flanges.

The following causes are all admitted to have an effect on sharp flanges, besides or in addition to, the effect of the form of the rail which is under discussion.

First.—Difference in diameter of wheels.

Second.—Trucks out of square.

Third.—Bad quality of wheels.

Bad gauging of wheels, unequal loading, etc., etc., are also admittedly aggravating causes.

While the existence of these defects is undoubted, often in an aggravated degree, yet there is a possibility which demands consideration, that they may produce sharp flanges when the rails are sharp cornered, and not produce them when the rail section fits the fillet of the flange. In view of the preceding conclusions as to the great comparative life of sharp-flanged wheels, if they be admitted to be correct, the question loses much of its importance, yet as those conclusions may not be admitted, it appears desirable to examine the probable effect of each of the above causes on sharp flanges.

Difference in Diameter of Wheels.

It is probable that few cast-iron wheels, mated on one axle, are exactly of the same diameter or exactly round. In not a few cases they are slightly out of center. In others they are of different hardness, so that if of originally the same diameter, they do not remain so. In others, again, the tread wears irregularly, so that the diameters are different in one position, although the same in another. In much less degree these conditions obtain with steel tired or dressed cast wheels. Great carelessness is often shown in mating wheels.

Mr. M. N. Forney, in the paper before referred to, demonstrates by results of experiments made with models, that even in a rectangular wheel-base, if the wheels are of different diameters, there is always a tendency to run in a curve. This tendency becomes very slight when the wheel-base is long, especially when the difference of diameter is small, but it always exists. Mr. A. M. Wellington, of your committee, has repeated these tests with a differently constructed apparatus, now in the possession of the Society, with the same result. If the wheels of only one axle are of different diameter, while the wheels of the other axle are of equal diameter, it is probable, although not demonstrated, that the tendency to run in a curve will be aggravated, for reasons which will be obvious on consideration.

Whenever there is the slightest difference in the diameter of the wheels, therefore, there will exist a tendency to roll toward one rail,

which must be continuously resisted by the flange; in other words, the flange reaction must continuously slide the wheels laterally on the rails. The power, or energy, wasted thereby will vary with the distance slidden through in a given time, and will ordinarily be trifling, but the flange pressure or reaction will not vary, since it takes the same pressure in pounds to slide a body an infinitessimal distance as to slide it a greater one; or even a greater pressure, because of the higher coefficient of friction.

There must, therefore, on both curves and tangents, be a large proportion of wheels which are exerting a very considerable flange pressure against the rails. How large a proportion it would be impossible to estimate statistically, but this cause for running to flange is aggravated by another, which can be rudely estimated.

Trucks Out of Square.

It appears almost self-evident, although your Committee are not aware that it has been demonstrated, that a truck out of square will have a tendency to run to flange even if the axles are parallel. If the axles are not parallel, there will certainly be such a tendency. To fit the axles to run in a 1 degree curve they need only be $\frac{1}{20}$ of an inch out of square. Car trucks, especially for freight, are often rudely made, without much attempt at more minute precision than this, and the statistics gathered by your Committee afford some measure of the resulting tendency to run to flange in the difference in number of sharp flanges in the freight trucks and passenger trucks.

On the Pennsylvania Company lines (Pittsburg, Fort Wayne and Chicago) the percentage of sharp flanges in worn out wheels only is only 11 per cent. in passenger against 20 in freight. On the Chicago, Burlington and Quincy, percentage of all removals, the figures are 6.4 passenger against 21.5 freight. The high percentage given for steel-tired passenger wheels (47.3) may be thrown out of account, for our present comparative purpose, for reasons given in the letter of Godfrey W. Rhodes, Superintendent M. P., subjoined to this report.

Other accompanying data, although not so directly comparable, afford cumulative evidence to the general fact, which is all your Committee can attempt to establish, that with all other conditions approximately equal, a much larger percentage of sharp flanges results in freight trucks than in passenger trucks.

It is probable that from the continued effect of irregular diameters and trucks out of square, a very large proportion of the wheels are subjected to a tendency to run to flange or away from flange; perhaps nearly all of them, and certainly a much larger proportion than finally obtain sharp flanges, so that one or the other of these defects is the first provoking cause of all sharp flanges. That this is so is clearly indicated by another fact of great importance in relation to this question, which

we may now establish, that with very rare exceptions sharp flanges occur only on one axle and are mated with wheels which wear away from flange.

If then other causes combine, such as bad quality, bad chill in the fillet, sharp cornered rails or what not, a sharp flange results; otherwise not. After establishing the fact just noted we will proceed to estimate the light which statistics shed on each of these latter causes.

Sharp Flanges Occur on One Wheel Only.

So far as your Committee can ascertain, it is practically an invariable rule that only one wheel on an axle has a sharp flange, and by far the most common rule that the opposite wheel is worn away in the tread from flange. Fig. 3, selected by mere chance as the first example of a series of worn sections which came to hand, and made to decide an entirely different question from that now under consideration, illustrates this fact sufficiently well. Out of the sixteen sections shown there are five which show some tendency to wear to flange. In every case the other wheel on the same axle shows an equally marked tendency to wear away from flange.

At the 1883 Master Car Builders' Convention, Mr. Richard Williams, an English mechanical visitor, whose experience had been such as to entitle his opinion to respect, declared as a part of a quite extended discussion, "I defy any of you to say you ever saw two sharp flanges on the same axle," and no one took up the challenge except one member, who suggested that the claim was a little too sweeping. In a paper signed C. E., written by Mr. A. M. Wellington, of your Committee, and published in the *Railroad Gazette* of March 27, 1885, this language was quoted, and it was added: "Modifying Mr. Williams' challenge so as to except wheels which have rendered full mileage before condemnation, the chances are strong that not a single instance can be found anywhere. Certainly, the exceptions are so rare as merely to prove the rule."

This challenge was taken up in a following issue of the *Railroad Gazette* (April 10), by Mr. R. H. Fowle, an Inspector of the Pennsylvania Railroad at the Jersey City shops, in which he stated that he "found that two sharp or worn flanges on the same axle are very common," alleging that he had found two cases in a single lot of 70 wheels, but this assertion was in turn controverted, May 8th, 1885, by Mr. J. N. Barr, Mechanical Engineer (now Superintendent of Motive Power) of the Chicago, Milwaukee and St. Paul Railway, in the following words:

"I was very much surprised at the remark made by a correspondent in the *Railroad Gazette* of April 10th, who says 'two sharp or worn flanges on the same axle are very common,' the same apparently being the result of experience on the Pennsylvania Railroad. The following rule has long been in force on this road and on several others with regard

to using second-hand wheels which are good for further service: 'Wheels showing a tendency to wear at the flange should be mated together; also, wheels showing a tendency to wear away from the flange.' Are not the wheels referred to some that have made a second run and that have been remated in accordance with the above rule?

"As a matter of fact, I would say, after having made this particular point one of careful observation for ten years, that it is an extremely rare occurrence to find two sharp or much worn flanges on the same axle on the first run of the wheels. Two worn flanges on the same axle have been caused by reversing the wheels in the truck after one of the wheels showed considerable flange-wear, but even this often fails to prevent the continual wear of the flange that was worn before the wheels were reversed.

"Any well-conducted wheel record that gives the defects or conditions of each wheel of a pair, will show conclusively that the wear of flanges is confined almost exclusively to one wheel of a pair. From such a record the following figures are given: During the past month forty-five wheels drawn from passenger cars have been reported 'worn flange,' and *in every case* (italics as quoted) the mate wheels are reported either worn tread or worn hollow away from the flange. As to the accuracy of these reports, it should be added that nearly all of these wheels have been twice inspected, first by the men removing the wheels, and secondly by the general inspector for the whole road. The only exception to the double inspection is for wheels that are found good enough to transfer directly to freight cars without being removed from the axles.

"The conditions shown by this months' record repeats itself month after month and year after year, as I have had abundant means of proving.

"Without attempting to theorize in the matter, I present the above merely as a fact; and the question of shape of flanges and rails, which is now being carefully discussed, is of too much importance to be obscured by facts which apparently bear on it, but which, on further investigation, are found to be due to causes which have no bearing whatever on the questions at issue."

Mr. Barr is a gentleman of high standing as a mechanical engineer, and his assertions and explanation would appear to completely neutralize the force of the inspector's statement, which is the only definite claim that two sharp-flange wheels are, in a practical sense, ever found

---

Fig. 3 (on opposite page), illustrates the comparative wear of opposite wheels on the same axle.

It consists of a series of diagrams, reduced to two-thirds of the original size, prepared by Mr. J. Townsend, General Foreman Car Department, Chicago and Alton Railroad, for the Congdon Brake Shoe Company, to illustrate the effect of that device, and not with any reference to flange-wear. He says in regard to the sections:

"The diagram shows the wear of eight steel-tired wheels under Chicago and Alton Baggage Car 40, which was put into service November 11, 1883, also diagram of eight steel-tired wheels under Baggage Car 43, which was put into service November 12, 1883, both cars and wheels being new.

"On the wheels of each car, four Congdon shoes and four common shoes were applied, accurate templates being made at the time, and number of each wheel taken on which the shoes were placed, and is shown in diagram by the plain line.

"At the expiration of six months, the cars having been in constant service between Chicago and St. Louis, accurate templates of the wheels were again made, which are indicated by the dotted lines in the diagram, thus showing the exact wear of the wheels on which were placed the Congdon as well as the common shoes."

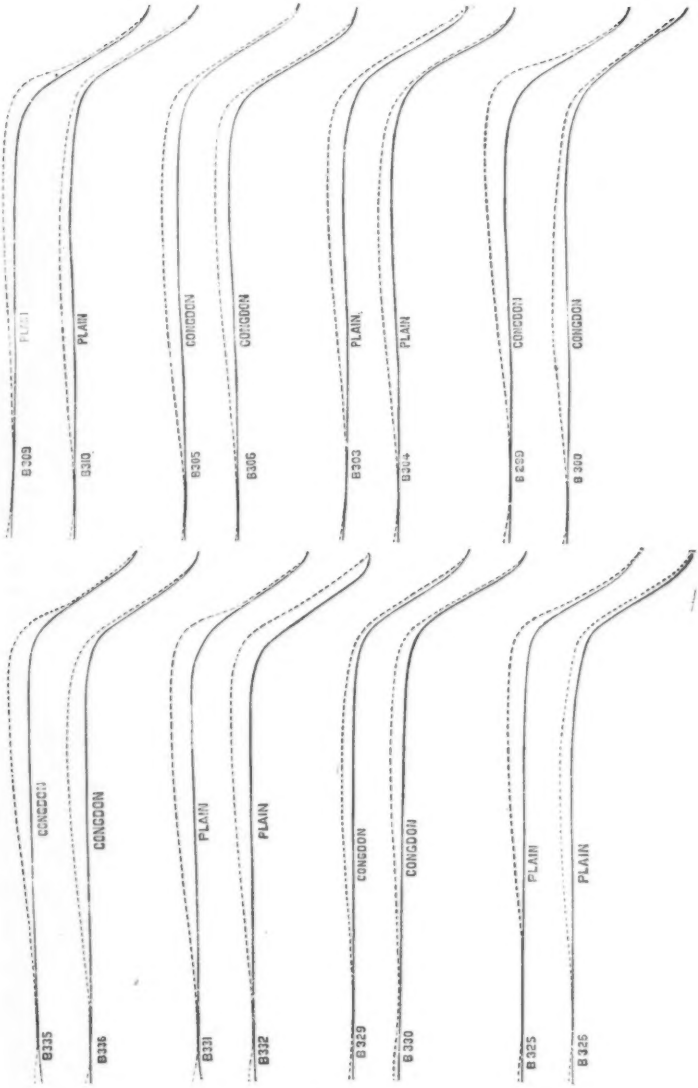

B 309
PLAIN
B 310
PLAIN
B 305
CONCOON
B 306
CONCOON
B 303
PLAIN.
B 304
PLAIN
B 299
CONCOON
B 300
CONCOON
B 335
CONCOON
B 336
CONCOON
B 331
PLAIN
B 332
PLAIN
B 329
CONCOON
B 330
CONCOON
B 325
PLAIN
B 326
PLAIN

FIG. 3.

on one axle, which your committee have been able to ascertain. The following has further bearing on this question.

On May 29th of the same year a letter was published from Mr. J. D. Hawks, M. Am. Soc. C. E., Chief Engineer of the Michigan Central Railroad, in which he makes the following statements:

"If it can once be settled that the shape of the rail has nothing to do with causing sharp flanges, we can then proportion our rail so as to get the greatest bearing surface for the wheels for each weight of rail. A general master car-builder of a trunk line writes me that 'forty-six 42-inch wheels, with standard tires, under the 60-foot post-office cars running between New York and Chicago, have made an average of 188 123 miles, and not a sharp flange among them. I am pretty certain that sharp flanges are the result of having one wheel on an axle softer than the other.'

"I have noticed many sharp flange wheels taken from under freight cars, where the wheel having sharp flanges shows much wear of the tread close to the flange, while the other wheel on the same axle shows a groove worn in the tread at quite a distance from the flange. This certainly has a tendency to prove that in such cases the sharp flange crowds against the rail on straight lines as well as on curves, and as the wheel without the sharp flange runs on the outside rail of curves as much as the wheel with sharp flange, it seems to show that the flange is worn sharp on straight lines, and that shape of rail-head has nothing to do with causing the sharp flange.

"We have on the Michigan Central one division, the Canada Southern, remarkable for its light percentage of curves. Mr. A. F. Bull, Master Mechanic of that division, says in answer to inquiry:

"I find that in the twenty-six months ending March 1st, 1885, we took out 69 wheels from under engines and tenders on account of sharp flanges. This is 3½ per cent. of the total wheels removed for all causes. Of these wheels, 31 were leading engine truck wheels, 10 trailing engine truck wheels, 17 leading tender truck wheels, and 11 trailing tender truck wheels. But this does not prove that there are more sharp flanges on leading axles, as we leave the trailing wheels on longer."

"That the part (if any) played by curves in causing sharp flanges is very small, is, I think, shown by the above report, as it is not disputed that the trailing wheels do not crowd against the outside rail in rounding curves."

From all the preceding, as well as from personal observation and experience, your Committee see no escape from the conclusion before announced, that, with hardly an exception, there never is but one sharp-flanged wheel on one axle, the other wheel being as a rule worn away from flange. If so, it indicates unmistakably that the primary cause of flange wear is not the rail, but some cause or causes which lead the axle to run more toward one rail than the other. For, since each wheel is subjected to precisely the same rail-wear, if the form of the rail only caused the flange-wear, we should expect to find each wheel equally flange-worn. If it was partly the rail and partly some other cause, tending to make the axle to run to one rail, we should expect to find both wheels somewhat flange-worn, but one wheel much more than the other. Only in the case that the form and area of the normal rail-contact had

no effect to cause flange-wear, and it was wholly caused by a tendency of the axle to run to one rail, should we expect to find one wheel flange-worn and the other worn away from flange. This latter having been shown to be the case, the only possible logical conclusion therefrom is that the form of the rail has no effect whatever in itself to cause sharp flanges, apart from defects of truck or wheel to make the truck run out of true.

Effect of Quality and Make of Wheels on Sharp Flanges.

The evidence which your Committee have collected appears to indicate that the quality of the wheel has a very marked and decided influence on the proportion of sharp flanges, so much so that the proportion of sharp flanges is sometimes from four to twenty or even fifty times as great with one make of wheels as with another, the almost invariable rule being that the poorer wheels have much the larger proportion of sharp flanges. This fact also, if it be admitted to be such, clearly tends to indicate that the form of the rail has very little to do with sharp flanges. For, since both good wheels and bad wheels run over the same rails in the same kind of trucks (in the cars of any one road), the wear due to peculiarities of the rail should be distributed alike between flange and tread. Both flange and tread might be expected to wear faster in a bad wheel than in a good one, but there is no reason why the relative wear of either part should be faster in a bad wheel than a good one. On the other hand, the most difficult part of a wheel to get a good chill on is the fillet of the flange, and it is but natural that badness of a wheel should show there first.

The correctness of this reasoning is supported by experience with wheels "slid flat."

In respect to such wheels your Committee find that, so far as the evidence which they have been able to collect can show, the percentage of failures from that cause is very nearly the same with good wheels and bad wheels, although the absolute number is much greater with bad wheels. It is to be expected that any exterior cause of wear, acting exactly alike on all wheels, like sliding or the form of rail, will have the same proportionate effect.

On the contrary, the ratio of wheels removed for sharp flange to those removed for worn tread or worn out, appears from some evidence of a high character to be enormously greater with bad wheels than good wheels, and your Committee find no evidence to the contrary.

The best evidence obtained as to this effect of quality is an elaborate statement of the wheel removals of 1884, by makers and causes, on the New York, Lake Erie and Western Railroad, given in the Appendix, and abstracted by percentages in Tables Nos. 6 and 7. This statement covers 15 595 removals from 250 973 wheels made by twenty-four different makers, which were numbered by the mechanical department in

TABLE No. 6.

PERCENTAGES OF WHEELS REMOVED in 1884 for various causes of each one of twenty-four different makes, on the New York, Lake Erie and Western Railroad, out of a total of 250 973 wheels and 15 595 removals; wheels by twenty-four different makers.

(Deduced from the Record of Table D, Appendix.)

CLASS I.—SIX BEST MAKERS.—Aggregating 78.2 per cent. of all wheels in service.

MAKERS.	Cracked and Broken.			Shelled out.	Sharp flange.	Slid flat.	Worn flat and worn out.	Total.	Percentage removals to number in service.
	Broken.	Cracked.	Total.						
1	1.2	7.2	8.4	0.3	4.8	9.6	76.9	100.	3.85
2	2.7	6.8	9.5	1.7	1.9	22.9	64.0	100.	3.69
3	0.5	14.9	15.4	0.6	1.6	25.9	56.6	100.	7.40
4	5.3	10.1	15.4	0.7	4.8	29.7	49.4	100.	3 00
5	2.0	23.2	25.2	0.6	2.6	35.0	36.6	100.	2.28
6	3.0	20.8	23.8	0.0	1.2	11.3	63.7	100.	8.97
Average.....	2.0	12.2	14.4	0.7	2.7	22.3	60.1	100.	4.39

CLASS 2.—SIX NEXT BEST MAKERS.—Aggregating 17.2 per cent. of Wheels in Service.

7	2.4	17.0	19.4	0.0	6.9	20.8	52.9	100.	8.21
8	2.5	12.2	14.7	0.1	16.1	20.4	48.7	100.	14.63
9	2.8	30.8	33.6	0.1	6.4	21.0	38.9	100.	9.26
10	1.5	27.9	29.4	0.1	2.9	18.8	48.8	100.	10.88
11	1.3	9.7	11.0	0.3	23.2	33.2	32 3	100.	22.50
*12	3.1	13.8	16.9	0.0	6.1	40.1	36.9	100.	8.23
Average.....	2.2	23.7	25.9	0.1	8.2	21.1	44.7	100.	10.94

CLASS 3.—TWELVE WORST MAKERS.—Aggregating only 4.6 per cent. of Wheels in Service.

MAKERS.	Cracked and Broken.			Shelled out.	Sharp flange.	Slid flat.	Worn flat and worn out.	Total.	Percentage removals to number in service.
	Broken.	Cracked.	Total.						
13	0.9	71.9	72.8	0.0	0.0	22.3	4.9	100.	14.40
14	3.4	59.3	62.7	0.0	0.0	23.7	13.6	100.	3.76
**15	10.4	19.6	30.0	0.3	14.2	11.9	43.6	100.	90.50
*16	0.0	0.0	0.0	0.0	54.6	45.4	0.0	100.	35.70
***17	6.3	21.9	28.2	0.0	21.8	9.4	40.6	100.	12.62
**18	4.9	14.5	19.4	0.0	24.1	17.8	38.7	100.	19.10
**19	7.9	8.6	16.5	0.0	9.3	14.3	59.9	100.	76.90
*20	1.6	22.9	24.5	0.0	4.9	15.6	55.0	100.	14.10
*21	6.0	36.2	42.2	0.0	4.6	17.4	35.3	100.	28.90
22	0.2	88.8	90.0	0.0	1.6	7.0	1.4	100.	25.20
23	5.8	26.4	32.2	0.0	3.3	49.6	14.9	100.	5.00
***24	7.5	4.5	12.0	0.0	8.9	44.7	34.4	100.	2.29
Average.....	4.4	37.2	41.6	0.0	12.4	20.3	25.7	100.	20.16

Bold face numbers represent makers having from 20 000 to 50 000 wheels each in service. Starred numbers indicate the smaller makers, viz.: *, less than 1 000 in service; **, less than 500 in service; ***, less than 300 in service.

NOTE.—Statements covering the years 1885, 1886 and 1887 have been received since the preparation of this report and show substantially the same facts as the records of 1884.

order of relative merit, according to their best judgment, without a thought of the bearing of the table on this particular question. Because of being thus graded, and because few roads have so large a number of wheels from so many different makers, and with such careful records to abstract from, this record has particular interest, The following is a summary of the percentages deduced from the table in the Appendix, as given in Table No. 6.

TABLE No. 7.

SUMMARY of the percentages of wheels removed in 1884 on the New York, Lake Erie and Western Railroad for various causes.

	Six best makers.	Six next best.	Twelve worst makers.	Average of all on road.
Per cent. of whole number in service	78.2	17.2	4.6	100.0
Broken	2.0	2.2	4.4	2.4
Cracked	12.2	23.7	37.2	19.4
Broken and cracked	14.2	25·9	41.6	21.8
Shelled out	0.7	0.1	0.0	0.4
Sharp flange	2.7	8.2	12.4	5.8
Slid flat	22.3	21.1	20.3	21.7
Worn flat and worn out	60.1	44.7	25.7	50.3
Total removed	100.0	100.0	100.0	100.0

PERCENTAGE OF TOTAL NUMBER IN SERVICE REMOVED FOR EACH CAUSE.

	Six best makers.	Six next best.	Twelve worst.	Total.
Per cent. of whole number in service	78.2	17.2	4.6	100 0
Broken	0.09	0.23	0.88	0.15
Cracked	0 54	2.60	7.50	1.20
Broken and cracked	0.63	2.83	8.38	1.35
Schlled out	0.03	0.01	0.00	0.02
Sharp flange	0.12	0.89	2.50	0.39
Slid flat	0.98	2.31	4.10	1.35
Worn flat and worn out	2.63	4.90	5.18	3.13
Total removed	4.39	10.94	20.16	6.21

The ratio of sharp flanges to wheels worn flat and worn out is:

Six best makers.....1 to 22.25
Six next best makers.....1 to 5.45
Twelve worst makers.....1 to 2.07

These makers, it should be always remembered, were not classified by number of sharp flanges, but according to their total characteristics, for deciding which the number of sharp flanges was only one of many details, and a very subordinate one.

This becomes apparent by comparing the single makers; No. 1 had 4.8 per cent. of sharp flanges, while No. 7 had only 1.2 per cent., the reason being that No. 1's wheels were a little softer, which gave fewer cracked and broken wheels. Not even the percentage of total removals was used as a basis of classifications, which latter, if examined, will be seen to have been on the whole very judicious, allowing more weight to safety from fracture than any single cause.

Summarizing the indications as to sharp flanges in a little different form :

Out of 1 000 wheels removed there were :

In 1 000 wheels made by the
- Six best makers, 27 sharp flanges.
- Six next best makers, 82 sharp flanges (3 times as many).
- Twelve worst makers, 124 sharp flanges (4.6 times as many).

Out of 10 000 wheels in service there were removed for sharp flanges :

In 10 000 wheels made by the
- Six best makers, 12 wheels.
- Six next best makers, 89 wheels (7.4 times as many).
- Twelve worst makers, 250 wheels (20.8 times as many.)

This leads to the striking conclusion, to the extent that one year's removals from 251 000 wheels by twenty-four different makers can give trustworthy evidence, that the same differences of quality have nearly twice as great an effect upon the number of sharp flanges as upon the number cracked and broken, as thus :

RELATIVE INCREASE IN NUMBER OF WHEELS CRACKED AND BROKEN AND IN NUMBER OF SHARP FLANGES, CAUSED BY DIFFERENCE OF QUALITY.

Comparison by percentages of wheels removed.

	Broken only.	Cracked and broken.	Sharp flanges.
Six best makers, standard of comparison.....	1.00	1.00	1.00
Six next best makers.....	1.10	1.80	3.04
Twelve worst makers.....	2.20	2.80	4.60

Comparison by percentages of wheels in service.

Six best makers, standard of comparison.....	1.00	1.00	1.00
Six next best makers.....	2.56	4.50	7.42
Twelve worst makers.....	9.78	13.28	20.83

[The comparison is made by dividing each percentage of removals given in the summary below the main statement by the percentage of the six best makers standing at the head of the column.]

This evidence is strengthened if taken in connection with the individual record. Thus, "No. 16" had 55 per cent. of his wheels fail for sharp flanges, the remaining 45 per cent. having all "slid flat;" the wheels, it would seem, being actually not good enough either to break, crack or wear. His immediate neighbors above and below, and likewise Nos. 8 and 11, differ from him only in degree, but do differ considerably. All their wheels were too soft. On the other hand, Nos. 10, 13, 14, 20, 21 and 22 have a very small proportion of sharp flanges (for such otherwise bad wheels), and the reason is indicated by the excessive number cracked and broken. Their badness lay in being too hard and brittle.

These conclusions are confirmed by the statistics given in the Chicago, Burlington and Quincy and other records of the Appendix, but in a less clear and decisive way, because of their narrower range. Your Committee therefore has not deemed it necessary to analyse them in detail, but simply refer to them. They find nothing in any of the figures which they have gathered which can be regarded as inconsistent with these conclusions.

Taking all the above figures together, and remembering that the best maker makes some bad wheels, it would almost seem as if differences of quality alone would explain all sharp flanges, without allowance either for trucks out of square, different sizes of wheels or effect of sharp rail corners. This still leaves it possible to suppose that there would be no sharp flanges even with bad wheels if the rail-corners were not sharp, except for the fact next to be considered.

Sharp Flanges a Normal Mode of Failure.

Your Committee deem it appropriate to here point out that a certain

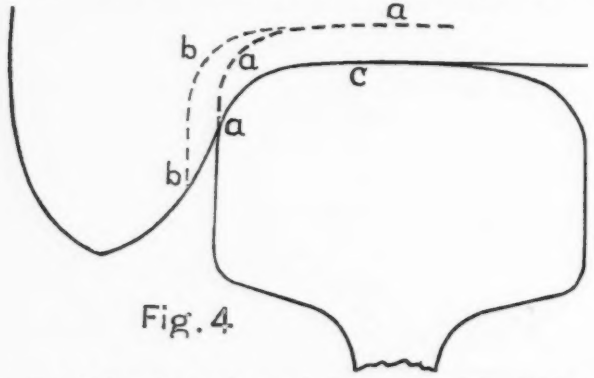


Fig. 4.

proportion of sharp flanges is a perfectly normal and inevitable result from the conditions, and in no case presumptive evidence of any defect

in proportion of either rail or wheel, even without considering the high relative mileage of such wheels before determined, nor does it appear to be a defect in its nature curable by any mode of wear or by any radius of rail corner.

Let us suppose a wheel running only on a perfectly straight road, and running so true that it has no tendency to run to or away from flange. Let us make both fillet and rail corner of large and identical radius, so that no question of the form of rail can come in. Let us suppose that there is no extra abrading friction results from the fillet contact *a c*, Fig. 4, but only normal rolling wear. The result of long service under such impossibly favorable conditions will ultimately be the worn tread *a a a*—which gives a sharp flange. Let there be the slightest tendency to run to flange, and we have the more pronounced case *b b a*. Only in case of tendency to run away from flange will the flange sections remain unmutilated.

Again, suppose the curvature to be so sharp, or the truck so out of square, that before any considerable tread wear results the flange is worn, and let the fillet and corner radii be large and identical as before. We then have the worn tread *c d d*, Fig. 5, and the large corner radius cannot help it.

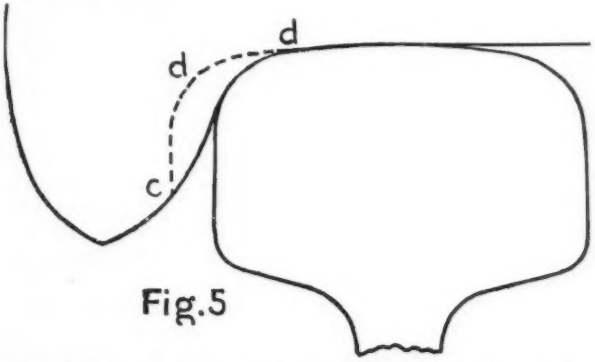


Fig. 5

Again, let us suppose as even as possible distribution of the wear between fillet and flange, so that the wear is on a parallel line with the original tread. We still have the straight flange wear *A A*, Fig. 6, and resulting thin flange.

It is therefore no cause for suprise or alarm that when worn out wheels only are considered, excluding wheels which "die young" from defects, the proportion of sharp-flanged wheels is large. If all wheels ran perfectly true the proportion of wheels which showed a decided tendency to sharp flange would be very large, if the above reasoning be correct, approximating to all of them. If we assume, however, as our

reasoning indicates, that practically all axles have more or less tendency to run to flange on one side, this relieves half the wheels of a tendency to flange wear and aggravates it in the other half, and we should expect

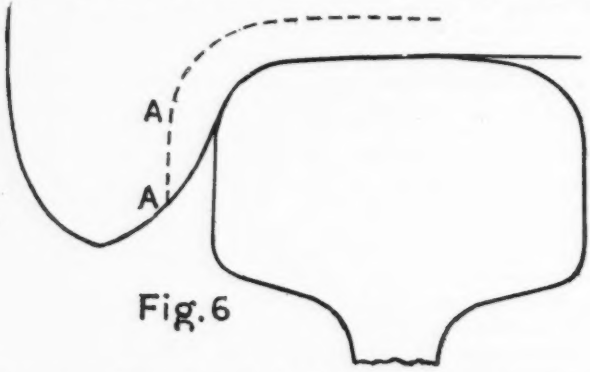


Fig. 6

with more confidence to find a full half the wheels, and no more, suffering from flange wear, whatever the radius of fillet and rail. The statistics herewith presented indicate strongly that when wheels which fail from legitimate wear only are considered, excluding failures from specific defect, this is in fact the case, but the surprising and significant fact is that the life of the flange-worn wheels does not suffer thereby.

Our investigations so far indicate:

First.—That a tendency to sharp flange is a natural phenomenon, which must exist and does exist in all perfect and perfectly running wheels, and is not eliminated by any form of rail or wheel.

Second.—That imperfections of diameter of wheels or of trucks, or both, give a tendency to run to one rail or the other to nearly all axles, relieving half the wheels of flange-wear tendency, and aggravating that of the other half.

Third.—That the quality of the wheel then has an enormous effect on the number of sharp flanges, causing many more when the fillet-chill is softer than the tread.

Fourth.—That when the wheel is sound and the quality even, about half the wheels get sharp flanges, while this proportion is reduced as the number of special defects increases, which cut short the life of the wheel before it is worn out.

Fifth.—That wheels which fail from flange wear are among the most durable of all wheels, if not the most durable, approximating to, if not exceeding, the life of those which fail from long-continued tread wear only, without developing other defect; so that no appreciable money

loss results from wheels running to flange instead of failing from tread wear only.

It remains to be seen, however, what form of rail does most to prolong the life of wheels which run to flange, and what form of flange does most to prolong the life of rails. Considerable statistical light may be thrown on this question from various technical observations of rail-wear on curves and tangents which have been made.

Rail-wear as Modified by Flange Contact.

In the year 1877 Mr. A. M. Wellington, of your Committee, made an investigation of the comparative life of steel rails on the Atlantic and Great Western (New York, Pennsylvania and Ohio) Railroad, the results of which were reported in a paper published in the pamphlet Report of the Road-masters' Meeting of 1878, and also in the *Railroad Gazette* of 1877. These investigations were undertaken for the primary purpose of determining the comparative wear of rails of various makes, and extended to rails of all makes on all kinds of alignment. They were made by determining the original weights of the rail by the carload invoices, removing the rails from the track and weighing them, taking an accurate section by a machine made for the purpose, determining the tonnage which had passed over them, and so determining the loss per yard in pounds per 10 000 000 tons of duty. In all, 145 steel rails were thus computed. The full tabular results are not reproduced here, since they can be easily referred to.

In 1879–80 a similar investigation was made on the Pennsylvania Railroad by Dr. Charles B. Dudley (Transactions Am. Inst. M. E., 1880), 64 rails having been used, 16 from level tangents, 16 from level curves, 16 from grade tangents and 16 from grade curves. Half of the rails from curves were taken from the outside rail and half from the inside rail, and half of each set were selected from the faster wearing rails and half from the slower wearing.

In neither of these papers was the possibility that the rate of wear on curves might vary with the age, and hence, form of the rails given any consideration, or even alluded to. Apparently the possibility did not occur to either of those conducting the investigation. Both papers appear to contain conclusive evidence that such is the case, however, especially when considered together; all the more conclusive because it was unconsciously collected and embodied in tables.

Your Committee know of no other investigations of the kind in this country or in England. Some have been made in Germany, which it has not appeared necessary to refer to further in this report nor to study in detail, since your Committee have reason to believe that they correspond in substance with the facts here presented.

The law of rail-wear on the outside of curves is well known. How-

ever sharp cornered the rail originally, the flange, in time, beds into it deeply, and wears it almost to its exact form, as shown in Fig. 11 below. The newer the rails the less the area of contact surfaces. As the rail wears the contact area becomes greater, until finally it includes nearly the whole flange.

Under these circumstances your committee cannot but regard it as highly significant to find in these records what certainly appears to be absolute evidence that, while the rail is new and the contact areas small, the rate of rail-wear on curves is very slow, but increases in a rapid geometric ratio (approximating to the square of the age in tons, apparently), as the rails become more worn. Since action and reaction are equal, a more rapid rail-wear implies also a more rapid flange-wear, so that if the above fact be admitted it necessarily implies that to imitate in the beginning the conditions which finally obtain from wear on the outside of curves, by making the rail corner and fillet fit each other from *A* to *B* in Fig. 2, is the reverse of good practice.

The following Tables, No. 8 and 9, give in part the evidence which these tests have to shed. There were these differences between the tests:

First—The Pennsylvania tests were made on much older rails, the newest being older in tonnage life than the oldest of the Atlantic and Great Western rails. All the curve rails, without exception, were badly flange-worn.

Second.—The Pennsylvania tonnage had a much less proportion of engines and larger proportion of cars than the Atlantic and Great Western, as did also the tonnage over the Pennsylvania level rails than the tonnage over the grade rails. This greatly affected the rate of tangent wear and curve wear alike, per million tons, making it necessary for comparative purposes to equate the observed curve wear of the Pennsylvania for a uniform tangent wear with the Atlantic and Great Western, on the assumption that the causes, whatever they were, which caused the tangent wear to vary, caused the curve wear to vary correspondingly. The table contains internal evidence that any error in this assumption must have been very small, not affecting the very marked contrast in wear of rails at different ages appreciably.

Third.—The Pennsylvania tests included a much smaller range of curvature, covering only 2, 3, 4 and 5 degree curves.

It will be seen in the following Table No. 9, that without a single exception which can be called such, the effect of age to increase the outside rail-wear is very marked indeed. That it was the change in the form of the rail and not the wearing through of the skin or other cause, which caused this difference of wear, is clearly indicated by the following Table No. 8, showing that the tangent rail-wear was more rapid in the newer than in the older rails.

TABLE No. 8.

TANGENT RAIL-WEAR OBSERVATIONS ON NEW YORK, PENNSYLVANIA AND OHIO (ATLANTIC AND GREAT WESTERN) RAILROAD, 1877.

RAILS OF LEAST AGE.		RAILS OF GREATEST AGE.	
Tonnage.	Wear in Pounds per 10 000 000 tons.	Tonnage.	Wear in Pounds per 10 000 000 tons.
5 526 580	1.24	26 441 000	0.85
6 000 400	1.30	24 788 000	0.85
11 819 800	0.16	21 050 800	1.05
11 259 800	0.66	20 574 800	0.82
14 364 000	1.63	20 574 800	0.44
14 364 000	1.92	20 574 800	1.11
14 364 000	0.63	19 831 000	0.51
14 364 000	0.90	17 433 300	1.09
14 364 000	0.56		
14 364 000	1.84		
Average....	1.084	Average....	0.84

Each of these observations includes the average of 2 to 6 contiguous rails, separately weighted and sectioned to determine loss. Here there is no sign whatever of any tendency to increased wear with age or tonnage duty, but the direct contrary, as was still more markedly the case with the Pennsylvania rails, a fact to be explained largely by the earlier rails being of far better quality than the latter ones. This same difference, presumably, runs through the following statistics in curve rail-wear, and if so, would indicate that the striking increase of curve rail-wear with age which appears, would be considerably greater if the effect of the better quality of the older rails could be eliminated.

TABLE No. 9.

RAIL-WEAR OF THE OUTSIDE RAIL OF VARIOUS CURVES AT VARIOUS TONNAGE AGES, as deduced from tests on the New York, Pennsylvania and Ohio (Atlantic and Great Western) Railroad, showing the increasing rate of wear with age. Corresponding figures from the Pennsylvania tests, equated to correspond to the same rate of tangent wear (0.92 pounds per ton per 10 000 000 tons duty) added for comparison, and to extend the range of the table. (In both sets of tests the tangent rails showed the slowest wear for the greatest ages, or the reverse of the curves).

Curve.	Age of Rails in Tons.	Lbs. per yd. per 10 000 000 Tons.
One degree	1 932 200	1.18
"	14 364 000	0.90
"	14 364 000	0.84
Average, newer rails	10 220 100	0.97
One degree	17 433 300	1.36
"	20 574 800	1 21
"	23 920 000	1.16
Average, older rails	20 642 700	1.24
Two degrees (P. R. R. level average of 4 rails)	57 512 400	1.61
Three degrees	11 259 800	1.09
"	11 259 800	1.69
"	11 819 800	0.34
Average, newer rails	11 446 500	1.04
Three degrees	14 364 000	1.40
"	14 516 100	1.48
"	14 364 000	2 37
"	21 050 800	1.40
Average, older rails	16 073 700	1.66
Three degrees (P. R. R. level average of 2 rails)	46 998 800	2.75
Four degrees	11 950 000	0.81
"	23 136 000	2.42
"	35 910 000	1.74
Average	23 665 300	1.66
Four degrees (P. R. R. grade, slower wearing)	32 428 614	2.23
Four degrees (P. R. R. level, 2 rails)	45 071 000	2.67

Curve.	Age of Rails in Tons.	Lbs. per yd. per 10 000 000 Tons.
Five degrees	14 364 000	3.13
"	14 364 000	3.13
"	21 814 000	1.99
Average	16 847 300	2.43
Five degrees (P. R. R. grade, average of 8 rails)	40 129 300	2 30
Six degrees	6 000 400	1.48
"	11 514 000	1.52
"	14 364 000	2.42
Average	10 626 100	1.81
Eight degrees	5 526 530	2.62
"	5 526 530	2.91
"	5 526 530	3.80
Average, newer rails	5 526 530	3.11
Eight degrees	15 429 300	3.16
"	17 433 300	4.75
Average, older rails	16 431 300	3.95
Twelve degrees	6 000 400	6.92
Sixteen degrees	6 000 400	13.00

NOTE.—The Pennsylvania observed rail-wear, owing either to difference in quality of rails, or to the longer trains and less proportion of engine tonnage, or both (probably chiefly the latter), showed a much lower rate of tangent rail-wear per million tons on the low grades than on the high grades, and even on the high grades than on the Atlantic and Great Western. As the causes which modified the tangent wear would modify the curve wear *pro rata*, the curve wear was equated for the above comparative purposes as follows:

	Tangent Wear per 10 000 000 Tons.		Ratio.
Atlantic and Great Western	0.92	pounds.	1.00
Pennsylvania level grades, average	0.3845	"	$\frac{1}{2.393}$
" high grade, slow wear	0.540	"	$\frac{1}{1.703}$
" " fast wear	0.861	"	$\frac{1}{1.068}$
" " average	0.700	"	$\frac{1}{1.314}$

That these assumptions (as to equating for a uniform tangent wear) lead to correct results is indicated in a measure by comparing the 4 slower wearing and 4 faster wearing grade curve rails of the Pennsylvania tests, the observed actual wear for which was 1.291 pounds and 2.217 pounds. When multiplied by the above ratios they give almost precisely the same equated ratio, as given above.

The inside rails corresponding to the above outside rails show no sign of increase in rate of wear from age in either series of tests.

TABLE No. 10.

RAIL-WEAR OBSERVATIONS on the New York, Pennsylvania and Ohio (Atlantic and Great Western) Railroad, reclassified from Table No. 9, according to Age of Rails when observed.

[The wear is per 10 000 000 tons duty; the duty given is the average of all rails observed.]

	RAILS OF LEAST AGE.		RAILS OF GREATEST AGE.		General Average.	Excess for curve.	Excess per degree.
	Million tons.	Pounds wear.	Million tons.	Pounds wear.			
Tangent.	12.1	1.084	20.0	0.84	1.00	.....	.....
1°.....	10.0	0.97	20.5	1 24	1.10	.10	.100
3°.....	11.4	1.04	16.1	1.66	1.40	.40	.133
4°.....	12.0	0.81	29.5	2.08	1.66	.66	.165
5°.....	14.4	2.65	21.8	1.99	2.43	1.43	.286
6°.....	6.0	1.48	13.0	1.97	1.81	.81	.135
8°.....	5.5	3.11	16.4	3.95	3.45	2.45	.306
Average..	9.9	1.68	19.6	2.15			
12°.....	6 0	6.92	.....	.....	6.92	5.92	.492
16°.....	6.0	13.00	.....	.....	13.00	12.00	.750

	LEAST AGE.		MOST AGE.	
	Million Tons.	Pounds.	Million Tons.	Pounds.
Average total wear per 10 000 000 tons on all curves 1 to 8 degrees, inclusive.....	9.9	1.68	19.6	2.15
Deduct tangent wear.....	12.1	1.08	20.0	0.84
Excess of wear per 1 000 000 tons due to same curvature at different ages.....	9.9	0.60	19.6	1.31

The concluding lines of Table No. 10 indicate that the wear was as nearly as may be double as fast at double the age.

The conclusions reached above are confirmed independently by another method of analyzing these rail-wear tests. So far we have compared only rails of different age on curves of the same degree. If we compare the average of the rails of different degrees with each other, we are led to substantially the same conclusion by another road.

The slippage per 100 feet of track due to curvature is directly as the degree of curvature, and hence the resistance and the rail-wear should be, other things being equal. If, however, we take a lot of rails of substantially the same tonnage age but on widely different degrees of curvature, and compare them together, it is obvious that the rails on the

sharper curves will have sustained a much larger proportion of their mileage life, have been much more worn to the form of the flange, and hence, if it be a fact that the rate of abrasion increases with such wear, the older rails should show a much more rapid rate of abrasion.

The Pennsylvania tests are too limited in range of curvature, and the rails were all too nearly worn out, to admit of comparison on this basis, but the Atlantic and Great Western were all comparatively new and about the same age (those on the sharpest curves the youngest), and it was found that with observations taken under these conditions the excess of curve rail-wear was as the square of the degree of curvature. In his report of these tests (p. 145) Mr. Wellington stated:

"It is evident from the table that the wear increased considerably faster than the degree of curvature, and it was found that the following empirical formula *fitted the observed facts* (italics as quoted) as nearly as any which could be devised, viz.:

"*Extra wear due to curvature in pounds per yard per* 10 000 000 *tons duty on a d degree curve* $= 0.03d^2$."

And hence,

"*Total wear of rails on a d degree curve in pounds per yard per* 10 000 000 *tons duty* $= 1 + 0.03d^2$.

"In the two following lines is given the wear according to this formula, directly opposite the average observed wear, and the closeness with which the two correspond can be seen.

Observed rate of railwear in pounds, per 10,000,000 tons duty, on a curve of

1°	3°	4°	5°	6°	8°	12°	16°
.10	.40	.66	1.43	.81	2.45	5.92	12.00

Computed rate by formula

.03	.27	.64	.75	1.08	1.92	4.32	7.68

"It is not pretended that this formula is strictly correct, even in theory, but several theoretical considerations indicate that it may be nearly so."

If we remember in connection with these figures, (1) that they included both inside and outside rails, only the latter showing a tendency to flange wear; (2) that the rails on the sharper curves were much younger than on the easier ones, so that the full contrast had not developed, and (3) that the rate of tangent rail-wear of the same rails seemed rather to decrease with age, these figures seem to your Committee to be strong evidence that the rate of rail-wear grows very materially greater as the rail corner is rounded off to fit the fillet of the flange.

Theory indicates that this should be so, because the flange has a longer bearing on the side of the rail, as does also the following additional practical evidence: The old Pennsylvania standard rail was sharp-cornered, with a $\frac{5}{16}$-inch radius; the new one has a $\frac{5}{8}$-inch radius.

These two rails have been examined in parallel tangent tracks by members of your Committee, the old pattern rails being eleven years old and the new pattern only one year old. The old pattern has lost considerably in height, but the rail corner is even sharper than when new, and there is no sign of flange wear. The new pattern is already badly flange-worn for fully $\frac{3}{4}$-inch below the top of the rail, the appearance being that as much metal has been lost off the corner of the rail as on top, and the first impression conveyed being that the track is wide of gauge. It was found on trial that this was not at all the case, however, but that the gauge was full.

Some of your Committee have also observed that the same thing is true of the round-cornered Lehigh Valley rail. Wherever this rail is laid the rail is worn far down the side as if it were the outside rail of a curve, whether on curves or tangents.

The apparent evidence of the experimental records is that the radius of rail-corner which results in least abrasion to the rail, and hence presumably of wheel, is not over $\frac{5}{16}$ or $\frac{3}{8}$-inch, the original corner radius of the A. & G. W. rails tested, and that as the radius becomes larger from wear, and the fillet and flange contact larger, the rate of wear rapidly increases.

It is also a fact so well known that your Committee do not deem it necessary to establish it by further evidence than Figs. 32 and 33 above, that it is only the outside rails of curves which wear to a larger radius to fit the fillet. Whatever the original form, all inside and tangent rails wear in time to a very sharp corner. As an average of the whole United States, curves constitute about 25 per cent. of the whole mileage, and hence outside rails about one-eighth. To establish precisely what does occur, Mr. Thomas Rodd, of your Committee, caused the accompanying sections of worn rails to be taken (Fig. 7), as explained in the Appendix.

Similarly the fillet radius of wheels almost invariably increases with wear, even in flange-worn wheels (see Fig. 3), and so far as your Committee can ascertain, practically never decreases, even in flange-worn wheels. With rare exceptions the fillet radius becomes $\frac{3}{4}$-inch or more.

That the radii of rails and wheels finally become from wear quite divergent does not necessarily imply that they should be made so in the first place, but it does appear to imply that no difference of corner radius can have much effect to diminish flange wear.

So far, your Committee have considered this question purely from the light of experience, with no attempt to determine what theory indicates. It would be improper to draw any conclusions in so important a matter, however, without considering it from a theoretical point of view, which we now proceed to do.

Radii of the Worn Surfaces of Rails in service, Pennsylvania Company (see Fig. 7, next page). Summary of Radii in inches.

TANGENT RAILS—FAST SPEED.

Edgar Thompson steel, 1876, 60 pounds per yard, gravel ballast.

No. of Cut.	Corner Radii. Left.		Right.	
1	....	.265	1.16	.36
2	1.045	.355	0.71	.245
3	0.83	.230	0.82	.28
4	0.82	.23	0.815	.26
Average	0.900	.270	0.876	.286

TANGENT RAILS—SLOW SPEED.

Cambria steel, 1875, 60 pounds per yard, stone ballast.

No. of Cut.			Corner Radii. Left.		Right.	
5,	1875	Cambria	1.15	.20	1.15	.28
6,	"	"	0.53	.12	0.67	.215 / .008
7,	"	"	0.97	.27	0.63	1.65
8,	"	"	7.27	.37	0.51	0.85
Average			.844	.240	.740	.211

CURVE RAILS—FAST SPEED.

Pennsylvania West Virginia State line; 7 degrees, 20 feet; 6¼ inches elevation; stone ballast, Edgar Thompson steel, 1880; 67 pounds per yard.

	Outside.		Inside.	
9	0.86	0.213	0.24	0.89
10	0.915	0.310	0.25	1.13
11	0.815	0.405	0.30	0.51
12	0.670	0.490	0.31	0.70
Average	0.815	0.355	0.275	0.81

CURVE RAILS—SLOW SPEED.

Six degrees; Wheeling Junction, 5½ inches elevation; stone ballast, Edgar Thompson steel, 1880; 67 pounds per yard.

	Outside.		Inside.	
13	....	.418	0.185	0.555
14	0.630	.485	0.285	0.615
15	1.390	.380	0.155	0.465
16	1.555	.455	0.345	1.045
Average	1.192	.434	0.242	0.670

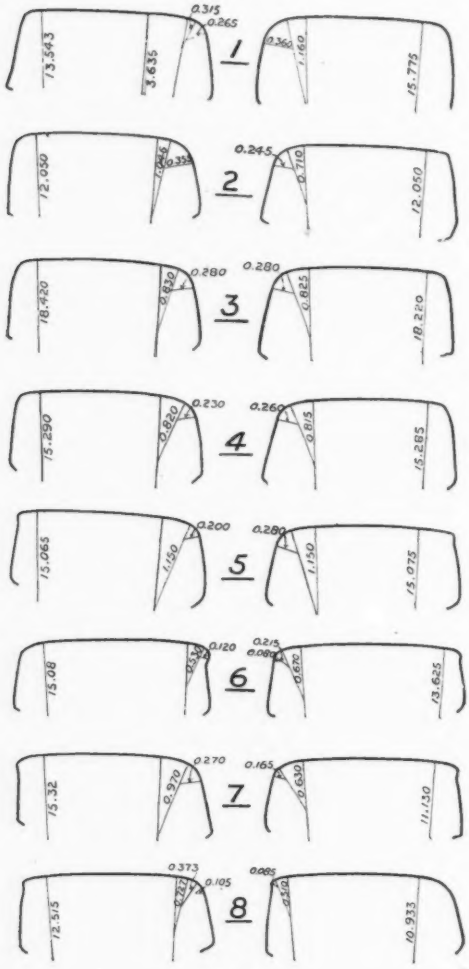


FIG. 7.

Radii of Worn Surface of Rails in Service, Pennsylvania Company.

Tangent Rails.

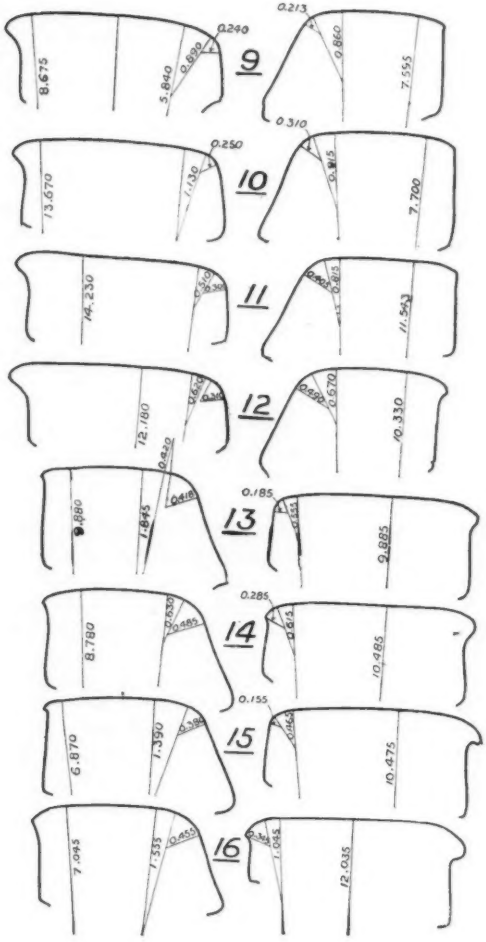


FIG. 7—*Continued.*

Radii of the Worn Surfaces of the Rails in Service, Pennsylvania Company.

Inside and Outside Rails of Curves.

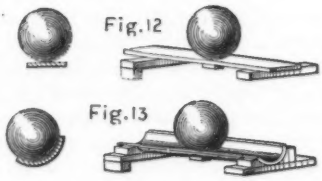
The Theory of the Question.

The wheel has been not unreasonably claimed as the greatest of human inventions, and the essence of the wheel is that its theoretical bearing surface shall be a mathematical line or point, affording no area of bearing surface whatever. In practice this is not strictly the case, owing to the elastic compressibility of the surface, but the bearing surface is always very small, nor can it be increased to advantage by making either wheel or bearing surface more compressible.

To such bearing surfaces the ordinary compression moduli of the text-books have no application whatever. These have been derived from experiments upon prisms, which have the same bearing surface as their greatest section or nearly so, and which fail from flowage or distortion long before the individual molecules of the material are seriously injured. To apply these constants to the bearing surfaces of spheres, or of cylinders laid on their side, or to draw the conclusion that pressures exceeding them are therefore dangerous or destructive, is entirely unwarranted. No attempt has ever been made, nor can there well be, to determine constants for such round bodies per square inch, but on the knife-edges of large scales, which have an angle of some 75 degrees only, and must be and remain practically unworn and uninjured, a load of 7 000 pounds per lineal inch of edge (3½ tons) is considered good practice, or nearly as much as rests on a wheel. If we allow for the difference between this sharp edge, which sustains a continuous load, and the flat tread of a wheel which sustains a load for an instant only, it would warrant an enormous load per square inch of bearing surface. In good bridge practice it is considered entirely safe to load steel rollers rolling on steel up to the equivalent of 10 000 pounds per lineal inch for a 33-inch wheel.

The sphere also has a much less bearing surface than a cylinder of the same diameter, for the same load, yet cannon ball rollers render excellent service in bridge work, nor are your Committee aware that they have ever been claimed to be more destructive to the bearing surfaces.

In figures 12 and 13 we have two opposite conditions for a rolling sphere, and certainly it will be admitted that Fig. 12 shows the best conditions for least friction and wear, although the bearing surface is much less.



Comparative abrasive friction of a sphere, in Fig. 12 with only a point of contact, rolling on a plane, and in Fig. 13 with a bearing surface conforming to the form of the sphere.

Your Committee are not clear that, even if we consider the top bearing only, where no question of consequent rubbing friction comes in, it can be stated without many allowances that increase of bearing surface is in itself an advantage. They cannot regard it as by any means self-evident that less wear would result if each rail and wheel-tread were made a foot wide or even six inches wide. They are rather disposed to believe that it would be entirely disadvantageous.

To see why this is so we must consider what causes rail and wheel wear. It is far from true that, as has sometimes been carelessly assumed, the only wear, or the chief wear, results from crushing, either on curves or tangents. There are these three causes for wear:

First.—Direct sliding of wheel on rail, such as is generally admitted to cause substantially all the extra curve wear.

Second.—Molecular interlocking of the fibres, which is the cause of the wheels revolving instead of sliding, and wears and bends the fibres on their side.

Third.—Direct crushing and disintegration of the fibres from the effect of the insistant weight.

Of these three causes your Committee are decidedly of opinion that the last is by much the least important of all, and they are led to this conclusion by the fact that it seems easy to account for as much wear as occurs by the first two alone. The wear from the first two is most certainly not inversely as the area, but comes nearer to being directly as the area (the total pressure being the same), if brake experiments and others may be trusted. Take direct sliding wear on a tangent, for example. Whenever the wheels are of different diameter direct sliding occurs. It takes a difference in diameter of less than $\frac{3}{1000}$ of an inch $\left(\frac{33 \times 56\frac{1}{2}}{5730 \times 12} = .0271 \text{ inches}\right)$ to cause as much slipping as on a 1 degree curve. If the truck is out of square there is constant slipping, its amount depending on the curve in which the truck tends to run. If the flange impinges on either side there is further slipping, both laterally and because of the change in diameter of the wheels. All three of these causes are continually acting, and often to an aggravated degree.

The resulting resistance and abrasion comes from the interlocking of the fibres, and as such interlocking is the only source of propelling power, it must go on for the most part without directly crushing down the fibres, but simply by sliding past them.

In all such friction the wear is certainly very largely increased by having large areas and many fibres in contact. In brake shoes, for example, it is well known that large shoes have greater holding power than small, with the same pressure. So long as the wheel revolves the comparatively small frictional surface below affords as much resistance as the larger brake surface, but the moment the wheel stops, the smaller

surface below causes vastly less friction than the larger one, and your Committee cannot doubt that this is chiefly because there are a less number of fibres exposed to tearing abrasion, and consequently less work done on them. They see no reason why this should not likewise be the case with all the sliding which takes place from causes noted on the top of the rail. In ordinary vehicles, running on ordinary roads, it is not considered advantageous to increase the width of tires more than is necessary to prevent sinking into the surface. While this analogy is an imperfect one, your Committee cannot admit that larger contact of rolling surfaces, and certainly not of rubbing surfaces, results in any decrease of wear, and they see no reason for anxious efforts to accomplish what has never yet been accomplished for any length of time, a bearing surface for the tread extending over the entire top of the rail. This is on the assumption that the rolling contact is of a cylinder of uniform diameter. When we include the corner of the rail and a crowning top, resulting in a different radius of rotation, and hence introduce rubbing friction, the case becomes still clearer, as will next be considered.

In Fig. 2 (reproduced from Fig. 45 of Mr. Forney's paper, above-mentioned, showing the form of rail and flange therein recommended) the tread at B has a radius of $16\frac{1}{2}$ inches and the lower contact point at A a radius of about 17 inches. As wear proceeds the latter radius will become still longer. As the greater load rests at or near to B the wheel will roll on that point, and at all points of contact having a different radius, A or C, will partly roll and partly slide or grind continuously.

A simple computation will show that a difference of $\frac{1}{10}$-inch in the radius at any point $\left(\frac{4.9 \times 16.5}{5730}\right)$ will cause that point to slide as much as the outside (or inside) wheels must on a 1 degree curve. Hence, the point A is sliding on the rail as fast as the outside wheel would on a 35 degree curve, and the whole flange contact from A to B, as fast as the outside wheel would on a 15 to 17 degree curve. This must inevitably produce extra grinding wear, and as there is the same reaction of rail against wheel on curves of all radius (viz., that necessary to continuously slide the wheels laterally so as to change their direction of motion), it will have a tendency to approximate the outside rail-wear on all curves to that on 15 to 17 degree curves.

On the other hand, there can be no question that there is a certain minimum corner radius beyond which the corner cannot be sharpened without destructive wear. To produce an absolutely square section, for example, so that the diagonals of a square section will measure what theory requires, is impossible even in the laboratory. The corners become sharp as a razor, and even the pressure of the finger nail, not to speak of a car wheel, will abrade them so as to materially change the diagonal. A car wheel would produce the same effect with a corner of

quite appreciable radius, and the very least radius which is ever to be found in old rails under any conditions (see Fig. 7) is about ⅛-inch, nor do your Committee suppose that any one would maintain that rails should be rolled to less than twice that radius.

Between the two extreme limits of (1) an absolutely sharp corner, and (2) the same corner radius as that of the flange fillet, the conditions with new rails are represented by Figs. 8, 9 and 10, Fig. 11 representing the conditions which finally obtain with all rails on the outside of curves. As to how closely it is desirable to have the rail corner under these conditions approximate to the fillet radius the question appears to stand thus:

When the wheel from any cause tends to run against the rail and is restrained by the flange, the forces acting are (1) the vertical component of gravity; (2) the lateral component from the lateral thrust, whatever it is; and (3) the resultant of these three forces, acting at an angle more or less oblique. Under these conditions the laws of mechanics determine what must take place. The wheel will mount until it rolls on the corner with the bearing surfaces normal to the resultant line of pressure, and will then remain in that position. Whatever the respective corner radii, so long as they differ at all, the theoretical line of contact will be a point, and to the extent that compression of the material expands this point into a line, the bearing surfaces will still be normal to the pressure. As the wheel is not revolving in the plane of this resultant, there will still be a certain trifling amount of sliding friction, but the question is:

1. Will there be more or less grinding friction or abrasion under the conditions of Fig. 10 than under those of Fig. 11? It certainly seems to your Committee that there should be greatly less, and the rate of abrasion should increase when the conditions of Fig. 11 are attained and the two radii correspond, as the statistical facts above given seem to show.

2. Is it desirable that the corner radii in Figs. 9 and 10 should be nearly alike, or differ considerably?

So far as rubbing friction only is concerned there will be less wear if they differ considerably; so far as crushing action is concerned, there will be less as they approach each other. As a whole, it seems probable to your Committee that the very minimum rate may be when the fillet and rail radii are nearly alike, but not quite; but that they should be therefore made so in the beginning appears more doubtful for the following reasons:

The evidence seems to be that under all working conditions the rate of rail-wear is very much less before the conditions of Fig. 11 are reached than afterwards. It is therefore desirable to postpone the attainment of such conditions as much as possible. But if the radii be made nearly alike in the beginning we have but little metal to wear away before the conditions of Fig. 11 are attained. In proportion as

FIG. 8.

Flange acted on by little or no lateral force, but as close to rail as its form permits without such force.

FIG. 9.

Flange acted on by a moderate lateral force, as by impacts or oscillation on tangents. (The line C gives the resultant line of pressure, perpendicular to the bearing surfaces in contact.)

FIG. 10.

Flange impelled against the rail by a strong lateral thrust, as on outside rail of curves. (The line D gives the line of pressure, still perpendicular to bearing surfaces in contact. The wheel rises as shown until they become so.)

FIG. 11.

Worn outside rail on curves, having the bearing surfaces worn to conform to each other, as in Fig 2.

the corner is originally sharper we have more. That is to say, if we take the total metal available for wear in the head at 10 pounds per yard or 1 square inch, by using for the corner radius:

½	inch in place of	⅜	inch we add	14.08	per cent.	to wearing	section.
"	"	½	"	8.05	"	"	"
"	"	⅝	"	3.35	"	"	"

If the preceding indications are correct as to this being very nearly the metal of slowest wear in the wheel head, this is a serious loss, much larger than the above percentages alone indicate, and the question of which radius will give the lowest rate of wear in the new rail is less important than which gives the most metal to be worn away before the conditions of Fig. 11 obtain.

The same reasoning, if sound, applies conversely to the fillet radius of flange. The larger this radius the longer will it take to wear away enough metal to bring about the conditions of Fig. 11. The most usual fillet radius some years ago was ¾-inch, but ⅝-inch has lately been made standard by the Master Car Builders' Association, for the supposed purpose of approximating more nearly to the form of the rail-head, with some admitted disadvantage in manufacturing, because the smaller the radius the more difficult it is to get a perfect chill in the fillet. If the preceding deductions are correct a ½-inch radius is rather to be preferred for all reasons, but there is no particular necessity for having any single standard radius, either for rail or wheel.

The preceding report is submitted for discussion, as before stated, in order that all errors therein may be pointed out, and all available additional evidence brought forward before the Committee attempt to formulate a report giving final conclusions, which they hope to be able to do very briefly.

Respectfully submitted,

H. STANLEY GOODWIN,
A. M. WELLINGTON,
SAMUEL REA,
GEORGE S. MORISON,
THOMAS RODD,
JAMES ARCHBALD,
S. M. FELTON, JR.,
} *Committee.*

Statement showing defects, average mileage, and percentage of WORN-o

Vol. XIX, p. 46.

DEFECTS.	1878.			1879.			1880.		
	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.
Shelled out	115	88 639	23.00	189	64 241	32.36	162	74 647	30.16
Comby	7	73 193	1.40	17	47 591	2.91	15	53 591	2.79
Seams	5	88 705	1.00	7	75 798	1.20	5	69 350	0.93
Worn flat	75	77 132	15.00	79	80 969	13.53	64	86 745	11.92
Worn flange	146	83 049	29.20	141	90 280	24.14	189	85 508	35.19
Hollow at flange	43	74 051	8.60	45	81 092	7.71	21	79 781	3.93
Hollow from flange	104	91 129	20.80	79	95 428	13.53	75	93 318	13.92
Total									

DEFECTS.	1878.			1879.			1880.		
	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.
Shelled out	233	65 877	29.21	363	61 287	38.01	503	60 623	45.66
Comby	14	50 9-6	1.75	42	46 634	4.40	45	53 307	4.08
Seams	5	52 819	0.63	7	87 394	0.73	11	52 613	1.00
Worn flat	132	64 598	16.54	107	69 250	11.20	65	75 953	5.89
Worn flange	228	72 176	28.57	243	79 846	25.45	307	76 967	27.84
Hollow at flange	63	71 223	7.89	53	77 318	5.55	49	82 228	4 44
Hollow from flange	114	82 200	14.29	104	81 376	10.89	94	79 668	8.52
Total									

TABLE A.

Pennsylvania Railroad Company.

f worn-out Altoona wheels (wheels cracked or broken, slid flat, etc., excluded) removed

Baggage, Express and Postal Cars.

	1881.			1882.			1883.			
Per-centage.	No Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.
30.16	117	68 510	14.50	260	63 976	28 60	313	63 190	39.08	221
2.79	125	46 891	15.49	106	61 007	11.66	110	64 165	13.73	286
0.93	121	31 692	14.99	95	48 695	10.45	79	51 703	9.86	19
11.92	67	60 693	8.30	159	66 134	17 50	50	72 066	6.24	34
35.19	250	76 167	30.98	148	74 840	16.28	138	71 695	17.24	208
3.93	16	95 305	1.98	37	70 420	4.07	20	68 535	2.48	18
13.92	42	89 933	5.20	97	71 353	10.67	81	70 802	10.11	88

Combination and Emigrant Cars.

	1881.			1882.			1883.			
Per-centage.	No. Drawn.	Average Mileage	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No Drawn.	Average Mileage.	Per-centage.	No. Drawn.
45.66	300	59 024	22.54	343	51 989	21.90	408	45 671	32.93	281
4.08	188	44 612	14.12	128	54 115	8.21	114	54 356	9.20	312
1.00	109	23 200	8.19	143	37 867	9.17	64	44 563	5.17	16
5.89	94	57 134	7.06	201	57 781	14.88	102	52 237	8.23	70
27.84	453	62 509	34.03	436	69 323	27.95	281	67 723	22.68	258
4 44	38	76 016	2.85	88	64 587	5.64	37	49 905	2.99	53
8.52	104	70 997	7.81	201	68 371	12.88	176	58 435	14.21	151

removed from passenger equipment cars during years 1878 to 1887, inclusive.

	1884.			1885.			1886.			1887.		
	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.
	221	65 591	25.23	160	76 115	15.69	188	76 726	15.69	191	75 483	16.71
	285	68 222	32 65	397	71 719	38.92	391	72 644	32.64	379	70 369	33.16
	19	68 568	2.17	31	67 855	3.04	18	81 588	1.59	10	88 974	0.87
	34	62 531	3.88	18	73 728	1.76	37	77 977	3.09	22	78 368	1.92
	208	78 059	23.74	323	73 273	31.67	475	75 367	39.65	454	75 390	39.76
	18	58 855	2 05	20	79 904	1.96	17	72 034	1.42	14	59 866	1.23
	88	75 427	10.05	59	82 850	5.78	69	75 008	5.76	72	70 866	6.30
	.....	.....	.....	.....	.....	.....	.....	.....	.....	1 142	73 440	.....

	1884.			1885.			1886.			1887.		
	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.	No. Drawn.	Average Mileage.	Per-centage.
	281	44 451	24.31	197	50 493	15.52	241	55 388	11.34	199	58 237	9.59
	312	60 107	26.99	426	58 749	33.57	819	61 741	38.54	810	60 924	39.02
	16	57 333	1.38	27	56 718	2.13	27	56 881	1.27	19	62 916	0.91
	70	58 575	6.06	66	56 275	5.20	72	59 965	3.39	54	56 510	2.60
	258	60 329	22.32	356	56 701	28.05	718	55 534	33.79	698	60 919	33.69
	53	51 272	4.58	50	54 768	3.94	52	46 941	2.45	73	37 516	3.52
	151	55 151	13.24	136	57 287	10.72	190	53 574	8.94	219	50 504	10.55
	.....	.....	.....	.....	.....	.....	.....	.....	.....	2 072	58 624	.....

TABLE

PENNSYLVANIA RAIL

Statement of the total number of wheels drawn; total condemned for all cause

Vol. XIX, p. 46.

Baggage, Express a

	1878.		1879.		1880.		1881.		1882.	
		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per Worn f
No. worn flanges...	146		141		189		250		148	
Total drawn.....	1 208	12.09	1 873	7.53	1 898	9.96	3 152	7.93	2 535	5
Less good wheels fit for further service	395		603		556		754		467	
Total condemned for all causes.....	813	17.96	1 270	11.10	1 342	14.08	2 398	19.43	2 068	7
Less sliding.....	313		686		805		1 591		1 159	
Worn out.....	500	29.20	584	24.14	537	35.20	807	30.98	909	16

Passenger, Combinati

	1878.		1879.		1880.		1881.		1882.	
		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per Worn
No. worn flanges...	228		243		307		453		436	
Total drawn.....	2 083	10.95	3 104	7.83	3 884	7.90	4 943	9.17	7 379	
Less good wheels fit for further service	945		1 065		1 433		1 711		2 495	
Total condemned for all causes.....	1 138	20.04	2 039	11.92	2 451	12 53	3 232	14.02	4 884	
Less sliding.....	340		1 084		1 348		1 901		3 324	
Worn out.....	798	28.57	955	25.45	1 103	27.84	1 331	34.03	1 560	2

TABLE B.

ANIA RAILROAD COMPANY.

r all causes; and total worn out, with percentage of worn flange wheels in each class.

Express and Postal Cars.

1882.		1883.		1884.		1885.		1886.		18	
	Per cent Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Pe Wor
148		138		208		323		475	21.06	454	
2 535	5.84	2 465	5.60	2 418	8.60	2 204	14.66	2 255		2 298	
467		472		457		334		395		325	
2 068	7.16	1 993	6.92	1 961	10.61	1 870	17.27	1 860	25.54	1 973	
1 159		1 192		1 085		850		662		831	
909	16.28	801	17.23	876	23.74	1 020	31.67	1 198	39.65	1 142	

Combination and Emigrant Cars.

1882.		1883.		1884.		1885.		1886.		188	
	Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		Per cent. Worn flanges.		P Wor
436		281		258		356		718			
7 379	5.91	7 734	3.63	7 579	3.40	6 701	5.31	6 847	10.49	7 009	
2 495		2 029		2 344		1 760		1 435		1 313	
4 884	8.93	5 705	4.93	5 235	4.93	4 941	7.20	5 412	13.27	5 696	
3 324		4 466		4 079		3 672		3 287		3 624	
1 560	27.95	1 239	22.68	1 156	22.32	1 269	28.05	2 125	33.79	2 072	

lass.

	1887.	
		Per cent. Worn flanges.
	454	
	2 298	19.76
	325	
	1 973	23.01
	831	
	1 142	39.76

	1887.	
		Per cent. Worn flanges.
	7 009	9.80
	1 313	
	5 696	12.25
	3 624	
	2 072	33.69

Year 1885.

Number of wheels removed for sharp flange.	Number of wheels removed for other causes.	Total number of wheels.	Per cent. of sharp flange to total number.	Make of Wheel.	Average month in use for sharp flange.
2 078	7 092	9 170	22.6	Bouton	61
179	296	475	37.7	Griffin	60
33	182	215	15.3	Thatcher	129
85	329	414	20.5	Russell	74
93	373	466	19.9	Chicago	81
18	166	184	9.8	Detroit	70
41	129	170	24.1	Barnum	74
5	311	316	1.5	Griffin & Wells	39
4	27	31	12.8	Barney	46
5	119	124	4.0	St. Louis	73
3	10	13	23.1	Murry	61
2	....	2	....	M. C. R. R	67
2	81	83	2.4	Pullman	60
2	5	7	28.5	B. & O. R. R	87
	69	69		Bass	....
	90	90		18 other makes; no sharp flanges	....
2 550	9 279	11 829	21.5	Average	63

150	2 258	2 408	6.2	Bouton	42.875
2	21	23	8.7	R. G. W.	20.328
2	14	16	12.5	Pullman	57.804
2	2	4	50.0	Detroit	93.700
1	....	1		Bass	58.001
	1	1		W. C. W. Co	.....
	1	1		W. F. Co	.....
	1	1		Hannibal	.....
157	2 298	2 455	6.4	Average	43.534

158	154	312	50.6	Allen	99 563
8	22	30	26.6	"	52 912
12	8	20	60.0	Washburn	42.446
2	....	2		English spoke	15.891
	16	16		Alston	.....
180	200	380	47.3	Average 33 inches.	43 832
				Total average	89.241

TABLE C.

ND QUINCY RAILROAD COMPANY.—COMPARATIVE STATEMENT OF FREIGHT CAR WHEELS REMOVED O

85.

el.	Average months in use for sharp flange.	Average months in use for other causes.	Life sharp flanges—greater or less.		Number of wheels removed for sharp flange.	Number of wheels removed for other causes.	Tota of
			Months.	Per cent.			
.....	61	57	4 greater.	7.0 greater	2 370	8 167	
.....	60	54	6 "	11.0 "	203	714	
.....	129	156	27 less	20.9 less....	21	151	
.....	74	78	4 "	5.4 "	73	317	
.....	81	69	12 greater.	17.4 greater	101	400	
.....	70	38	32 "	84.2 "	18	267	
.....	74	77	3 less . ..	4.0 less....	31	184	
ls....	39	41	2 "	5.1 "	11	382	
.....	46	58	12 "	26.1 "	1	21	
.....	73	41	32 greater.	78.0 greater	22	121	
.....	61	106	45 less	73.8 less....	2	14	
.....	67	....			2	23	
.....	60	20	40 greater.	200.0 greater	4	....	
.....	87	37	50 "	135.1 "	1	43	
.....	....	44	.....	.....	6	74	
es; no						229	
es ...	....	....	.....	.....			
.....	63	59	4 greater.	6.8 greater.	2 866	11 170	

CAST-IRON WHEELS REMOVED FROM PASSENGER CARS.

			Months.	Per Cent.			
.....	42.875	26.841	16.034 greater.	59.7 greater.	212	1 848	
. ....	20.328	34.098	13.770 less. ...	67.7 less....	6	8	
.....	57.804	53.049	4.755 greater.	8.9 greater.	6	5	
.....	93.700	64.309	29.391 "	45.7 "	3	9	
.....	58.001	.....	.....	.....		8	
.....	.....	50.645	.....	.....		2	
.....	.....	17.076	.....	.....			
.....	.....	2.547	.....	.....			
.....	43.534	27.099	16 435 greater.	60.6 greater.	227	1 880	

STEEL TIRED WHEELS REMOVED FROM UNDER PASSENGER CARS.

			Months.	Per Cent.			
.....	99 563	101 263	1.700 less... .	1.7 less....	184	146	
.....	52 912	49.194	3.718 greater.	7.5 greater.	10	16	
.....	42.446	26.257	16.189 "	61.6 "	12	42	
ze.....	15.891	.....	.....	.....	12	8	
.....	.....	15 874	.....	.....	....	2	
nches.	43 832	33 615	10.223 greater.	30.41 greater.	218	214	
e	89.241	85.704	3.537 "	4.1 "			

EMOVED ON CHICAGO, BURLINGTON AND QUINCY RAILROAD.

Year 1886.

eels for	Total number of wheels.	Per cent. of sharp flange to total number.	Make of Wheel.	Average months in use for sharp flange.	Average months in use for other causes.	Life sharp flanges—greater or less.	
						Months.	Per cent.
	10 537	22.5	Bouton	61	61	....	
	917	22.1	Griffin	63	62	1 greater.	1.6 greater.
	172	12.2	Thatcher	135	165	30 less	22.2 less.
	390	18.7	Russell	83	85	2 "	2.4 "
	501	20.1	Chicago.....	83	82	1 greater.	1.2 greater.
	285	6.3	Detroit	72	41	31 "	75.6 "
	215	14.4	Barnum	124	92	32 "	34.8 "
	393	28.0	Griffin & Wells....	59	50	9 "	18.0 "
	22	4.5	Barney	73	70	3 "	4.3 "
	143	15.3	St. Louis	64	61	3 "	4.9 "
	16	12.5	Murry	92	109	17 less	18.5 less.
	25	8.0	Haskell	147	116	31 greater.	26.7 greater.
	4	....	St. Charles.....	26	....	.....	.....
	44	2.2	A. C. Treat.....	52	43	9 "	20.9 "
	80	7.5	Bass	89	53	36 "	67.9 "
	229		20 other makes; no sharp flanges ...	....	20	.....	
	14 036	20.4	Average.....	64	62	2 greater.	3.2 greater.

						Months.	Per Cent.
	2 060	10.3	Bouton	36.861	34.555	2.306 greater.	6.6 greater.
	14	57.1	M. C. B	72.201	61 964	10.237 "	16.5 "
	11	54.5	Detroit	67.189	81.631	14.442 less.....	21.5 less
	12	25.	Pullman	38.412	49.185	10.773 "	28.0 "
	8		R. G. W	.....	51.845	.....	
	2		Treat	.....	28.556	.....	
	2 107	10.8	Average.....	38.565	34.931	3 634 greater.	10.4 greater.

CARS.

						Months.	Per Cent.
	330	55.8	Allen	85.682	105.265	19.583 less	22.8
	26	38.5	"	86·308	44.187	42.121 greater.	95.3
	54	22.2	Washburn	75.983	70.371	5.612 "	7.9
	20	60.0	English spoke.....	34.541	23.998	10 543 "	43.9
	2		Alston	.....	30 086	.....	
	432	50.4	Average 33 inches.	64.393	57.570	6.283 greater.	11.8 greater.
			Total average	82.363	90.109	7.746 less	9.4 less

TABLE D.

Vol. XIX, p. 46. NEW YORK, LAKE ERIE AND WESTERN RAILROAD COMPANY.

Statement showing the whole number of wheels of the several makers, removed, cracked, broken, flat tread, shelled out, sharp flange and flat, by sliding on the New York, Lake Erie and Western Railroad, during the year 1884, with the average number in service per month.

Maker, in order of general excellence.	Cracked plate.	Cracked hub.	Cracked flange.	Cracked treads.	Cracked ribs.	Total cracked.	Broken treads.	Broken flange.	Broken.	Total broken.	Flat treads.	Shelled out.	Sharp flange.	Flat by sliding.	Total.	Average No. in service per month.
1	58	3	6	44	1	112	3	13	2	18	1 201	5	75	150	1 561	40 533
2	60	10	..	38	2	110	31	12	1	44	1 033	28	30	370	1 615	43 873
3	345	5	3	84	5	442	7	7	..	14	1 681	18	47	770	2 972	40 237
4	94	1	1	14	19	129	60	6	2	68	635	9	62	381	1 284	42 844
5	84	6	2	17	5	114	4	6	..	10	180	3	13	172	492	21 546
6	42	8	..	85	3	138	8	12	..	20	420	..	8	75	661	7 376
7	15	..	1	33	..	49	2	5	..	17	152	..	20	60	288	3 514
8	35	4	7	19	47	112	10	12	1	23	448	1	148	187	919	6 274
9	332	18	22	38	43	453	21	19	1	41	572	2	94	309	1 471	15 873
10	395	20	2	43	9	469	15	7	3	25	821	1	48	316	1 680	15 432
11	15	2	1	1	10	29	3	1	..	4	96	1	69	99	298	1 323
12	8	..	..	1	..	9	1	1	..	2	24	..	4	26	65	790
13	58	2	..	6	95	161	1	..	1	2	11	..	....	50	224	1 559
14	33	..	..	..	2	35	2	..	..	2	8	..	....	14	59	1 573
15	18	4	2	46	7	77	35	6	..	41	172	1	56	47	394	436
16	..	..	..	..	..	....	..	..	..	..	..	..	147	122	269	754
17	5	..	..	1	1	7	2	..	..	2	13	..	7	3	32	253
18	6	..	..	1	2	9	3	..	..	3	24	..	15	11	62	324
19	7	4	3	10	..	24	19	3	..	22	168	..	26	40	280	365
20	25	..	..	..	3	28	1	..	1	2	67	..	6	19	122	866
21	68	3	1	6	1	79	9	4	..	13	77	1	10	38	218	758
22	393	1	1	1	..	396	..	1	..	1	6	..	7	31	441	1 752
23	24	8	..	..	..	32	7	..	..	7	18	..	4	60	121	2 426
24	1	..	..	2	..	3	4	1	..	5	23	..	6	30	67	292
Totals	2 121	99	52	490	255	3 017	248	116	12	376	7 850	70	902	3 380	15 595	250 973

Percentages deduced from this table are given in Table 7.

The term "Flat Tread" includes all "worn out" wheels also.

The order of the makers, 1 to 24, was that which, all things included, was considered to represent the general excellence of the wheels, without reference to the number of sharp flanges except as one of many qualities of the wheel.

TABLE E.

Vol. XIX, p. 46. **WHEELS REMOVED BY THE LEHIGH VALLEY RAILROAD DURING THE YEAR 1886.**

Number of wheels removed for sharp flanges.	Number of wheels removed for other causes	Total number of wheels removed.	Per cent. of sharp flanges to total number.	Make of wheel.	Average months in use for sharp flanges.	Average months in use for other causes.	Life sharp flanges greater or less.	
							Months Decreased.	Per cent.
816	8 498	9 314	8.8	Hazleton	113	81	32 greater.	39.5 greater.
489	4 501	4 990	9.8	Catasauqua.....	101	83	18 "	20.5 "
36	855	891	4.0	Cayuta.....	96	57	39 "	68.4 "
22	286	308	7.1	Whitney	205	230	25 less.	12.2 less.
15	157	172	8.7	Lobdell	196	121	75 greater.	62.0 greater.
8	131	139	5.8	High Bridge	181	159	22 "	13.8 "
4	32	36	11.1	Jackson & Woodin	113	158	45 less.	38.9 less.
4	24	28	14.3	J. & N. Scoville.....	125	80	45 greater.	56.2 greater.
....	22	22	0.	Wilmington.....	....	233	..	....
....	12	12	0.	Lambertville.....	....	97	..	....
1	11	12	8.3	Washburn, Hunt & Co....	204	71	133 "	187.3 "
....	9	9	0.	D. L. & W.....	....	133	..	....
8	9	17	47.1	John McDougall	43	42	1 "	2.4 "
15	105	120	12.5	Thirty-nine others.....	72	78	6 less.	7.7 less.
1 418	14 652	16 070	8.8		111	85	26 greater.	30.6 greater.

This table has been abbreviated by condensing thirty-nine makers with one to ten wheels each into one line.

TABLE F.

Pennsylvania Company.

Wheels drawn on account of worn flanges, 1885 and 1886.

33-Inch Passenger Wheels.

Vol. XIX, p. 46.

Year drawn.	Worn out. No. of wheels drawn worn out.	Worn out. Average Mileage.	Worn out. Average Service. Yr.	Mo.	Da.	Sharp Flanges. No. wheel worn, flange.	Sharp Flanges. Average Mileage.	Sharp Flanges. Average Service. Yr.	Mo.	Da.	Per-centage worn flange.
1885	843	72 087	....	....	....	92	69 913	....	....	....	11
1886	612	90 833	....	....	....	65	85 705	....	....	....	11
.....	.....	.....	81 460	....	....	....	.....	77 808			

33-Inch Freight Wheels.

1885	4 742	.....	7	5	13	1 066	.....	6	5	4	22
1886	6 233	.....	7	7	21	1 139	.....	6	9	2	18

26-Inch Engine Wheels.

1885	127	90 088	....	....	..	29	87 117	....	....	....	23
1886	82	100 182	.. .	....	....	6	122 886	....	....	....	7

28-Inch Engine Wheels.

1885	203	85 534	....	....	....	27	76 306	....	....	....	13
1886	269	82 835	....	....	....	38	74 556	....	....	....	14

30-Inch Engine Wheels.

1885	501	79 618	....	....	....	109	79 324	....	....	....	22
1886	424	79 914	....	....	....	48	76 948	....	....	....	11

33-Inch Engine Wheels.

1885	767	73 505	....	....	....	182	73 660	....	....	....	24
1886	580	80 190	....	....	....	84	75 573	....	....	....	14
Average all engine wheels..	.....	83 933	....	....	....	.....	83 296				

TABLE G.

BOSTON AND ALBANY RAILROAD COMPANY, 1884.

Wheels Removed from Passenger Service.			Wheels Removed from Freight Service.		
Cause for Removal.	No. Removed.	Percentage.	Cause for Removal.	No. Removed.	Percentage.
Shelled out	65	26.970	Loose	14	2.19
Slid flat	78	32.365	Worn flat	277	43.28
Seamed	2	.829	Slid flat	67	10.47
Worn flat	6	2.489	Cut flange	19	2.97
Honeycombed	7	2 904	Broken	163	25.47
Sand holes	19	7.883	Chipped flanges	7	1.09
Worn out	51	21.161	Worn out	91	14.22
Broken plate	8	3.319	Chipped tread	2	.31
Chipped tread	5	2.075			
Total	241	99 995	Total	640	100.00

APPENDIX

TO REPORT OF COMMITTEE ON PROPER RELATION TO EACH OTHER OF THE SECTIONS OF RAILWAY WHEELS AND RAILS.

Letter from THEODORE N. ELY, Esq., General Superintendent Motive Power Pennsylvania Railroad, transmitting Table A.

ALTOONA, PA., June 15th, 1887.

In reply to your letter in regard to the percentage of wheels removed for sharp flanges, we have gone back over our records since 1878 and give you herewith the information asked for.

These figures show the percentages for the two classes of service which comprise the great majority of our passenger wheels.

The number drawn with sharp flanges from locomotive trucks will probably show a somewhat higher percentage than for passenger cars; this, however, is due to the fact that our inspection is somewhat closer for locomotive truck-wheels than for passenger-car wheels, as their duty is much more severe.

The percentages given are for worn-out wheels only, and do not comprise those removed from sliding, or that were again put in service. You will note that these percentages run from 16.28, the lowest, in 1882, to 39.65, the highest, in 1886. [In 1887, received since, it ran slightly higher.]

There is also sent with these statements, the percentages of average mileage of wheels drawn for the different defects named.

The percentage of average mileage of wheels removed for all causes shows that there is no great difference between those removed from worn tread (or "hollow from flange") and those removed on account of "worn flange."

In the majority of cases, however, those worn "hollow from flange" give the highest mileage, although in some years the reverse was the case. In all cases, however, the average mileage of wheels with these two defects was much higher than for the other causes.

We subdivide the wheels on these statements into two classes, for the reason that the service is quite different. The service of wheels under baggage, express and postal cars, which run principally on through trains with few stops, gives a higher average mileage than the wheels under passenger, combined and emigrant cars, which run principally on local trains, making many stops.

I am free to say that I do not think you will be able to make any deductions from these statements that will enable you to compare them with the percentages of sharp flanges or average mileage of wheels of other roads, for the reason that the service would probably be different, and we feel quite sure from the inquiries that we have made that the inspection of the Pennsylvania Railroad is much more rigid than most other roads, wheels not being worn so closely to their limit.

In this connection I would say that in discussing this matter it should be borne in mind that the shape of the wheel tread and flange cannot so easily be modified as the cross section of the rail, for, in order to get an even chill on the tread and flange, a fillet with a certain radius is found to give the best results, other things being equal.

We keep no record of freight wheels. They are made from same mixture as passenger wheel.

Second letter from Mr. ELY, transmitting Table B.

ALTOONA, PA., June 28th, 1887.

I send herewith a statement from 1878 to 1886, inclusive (Table B, printed in full) which shows the number of wheels drawn for sharp flanges; the total number of wheels drawn; the percentage of all wheels drawn except those which were put into service again, and the percentage for worn-out wheels; this latter percentage is the same as the one before sent you. This statement is in such a shape that you can make any combination of percentages you choose.

I do not think, however, that under any circumstances, the wheels that were good for further service should be used in the comparison of percentages. Many of them were removed because the mate was removed, and not from any fault of the wheel itself, and in the same way, those that were removed from sliding have no bearing upon the percentage for sharp flanges.

Letter of GODFREY W. RHODES, Esq., Superintendent Motive Power, Chicago, Burlington and Quincy Railroad Company, transmitting Table C.

AURORA, Ill., May 4th, 1887.

We send you with this a comparative statement (Table C) showing the number of cast-iron wheels removed from our freight-car equipment during the years 1885 and 1886; also the number of cast-iron and steel-tired wheels removed from our passenger equipment for the same years. The defects, you will observe, are put under two headings, viz.: Number of wheels removed for sharp flange and number of wheels removed for other causes. Under the column Make of Wheel, we show the different kinds of wheels. I do not know, however, as this has any special

bearing on the question under investigation. You will observe that in freight-car equipment the percentage of sharp flange wheels removed to the total number was:

In 1885	21.5	per cent.
" 1886	20.4	"

Under passenger equipment we find for cast-iron wheels removed for sharp flanges:

In 1885	6.4	per cent.
" 1886	10.8	"

In passenger equipment with steel-tired wheels this figure is largely increased:

In 1885	47.3	per cent.
" 1886	50.4	"

We account for this as owing to the fact that there are many defects in cast-iron wheels, such as shelled out, seams, chipped rim, worn hollow away from flange, etc., which do not occur with steel-tired wheels. Further, the wheels ruined by sliding are very much less with steel-tired wheels than with cast-iron. Many more steel-tired wheels therefore will remain in service constantly subject to flange wear than with cast-iron. Moreover, our steel-tired wheels are used mostly under heavy equipment fitted with 6-wheel trucks. It has been found that the middle wheel of the 6-wheel trucks, notwithstanding the fact that it has no brake shoes to it, wears much more rapidly than either of the other two pair of wheels, and after it has made some thousand miles will almost always be the smallest wheel. I think I am safe in saying it always gives out on account of flange wear and has to be turned down in order to preserve a safe flange and not on account of any wear on the tread.

Mr. W. A. Scott, until recently Assistant Superintendent Motive Power, Chicago and Northwestern, has made some very interesting investigations on this matter, and lately has been running some of his 6-wheel trucks without any flange on the middle pair, and I believe with perfectly satisfactory results. Some modification has to be made in the amount of journal-box play, I believe. If you wrote to Mr. Scott I am sure he would be glad to give you the result of his investigations. He is now Superintendent of the Madison Division at Baraboo, Wis. To show you the proportion of cast-iron wheels ruined by sliding under passenger equipment we give you the following figures for 1886:

Total number of wheels drawn, 2 107.

227	for sharp flanges	10.8 per cent.
932	" slid flat	44.2 "
948	" other causes	45. "
		100.

We have, comparatively speaking, but very few steel-tired wheels in passenger service, they are mostly under our Pullman assigned cars, fast mail and heavy baggage cars.

Letter from W. A. SCOTT, Esq., Superintendent Madison Division Chicago and Northwestern Railway, giving information referred to at close of preceding letter.

BARABOO, WIS., May 17th, 1887.

My investigation developed the fact that with a long wheel base (9 to 10 feet), 6-wheel truck, the center-wheel flanges were cut sharp more rapidly than end wheels, and as steel tires are expensive, we devised a journal box which made the use of center flangeless wheels absolutely safe, and then economized as follows: When end wheels of truck had worn flanges sharp, and they had been turned off until next turning would leave the tire too thin (less than $1\frac{1}{4}$ inches), we turned off flange entirely, thus leaving face of wheel flat, and probably $1\frac{1}{4}$ or $1\frac{3}{8}$ inches thick, and would get a heavy mileage out of this tire located in center; in fact, as much or more than could be obtained from it with flanges, because when flanges were worn sharp it was necessary to reduce tread thickness from $\frac{1}{8}$ to $\frac{3}{8}$ inch to secure new flange. It was frequently the case that we could not keep the flanges on a tire and get our 200 000 miles out of same, when by making it flat, when useless for further flange mileage, we could get that much more mileage from same tire, and I think even more, but we have not yet used them long enough to ascertain statistically just how much. My impression is that where 6-wheel trucks are used, one-third maintaining cost can be saved by using a flangeless center wheel, the end wheels (where steel tires ones are used) furnishing enough tire mileage that would otherwise be scraped to keep them going.

Letter from WILLIAM H. BROWN, Esq., Chief Engineer of the Pennsylvania Railroad.

PHILADELPHIA, June 28th, 1887.

I send you herewith some prints of rails lately taken on our road, showing the actual wear from the original section, in which you will notice that the round corner on the rails, which I have been fighting so strongly for the last ten years, is unnecessary, as the corners of the rails actually become sharper by use than when they were first laid.

[The nature of the blue-prints is so clearly explained by the letter that it has not been deemed necessary to reproduce them. They show on rails much worn on top corner radii of $\frac{1}{4}$ to $\frac{3}{8}$ inches.]

Letter from F. D. ADAMS, Esq., General Master Car Builder of the Boston and Albany Railroad, transmitting Table G.

ALLSTON, MASS., February 14th, 1885.

In answer to your inquiry, I have taken the pains to search our records to reach the information which covers your point.

You will notice that in passenger service no wheel was reported with sharp flange, which indicates, first, that trucks are kept square and in good ordinary condition; and second, that the cast-iron wheel for heavy passenger service will not last long enough, with reasonable care as to exactness in fitting, etc., to wear at the flange sufficient to be condemned for that cause.

The term broken plate could more properly, undoubtedly, be classed as crooked plates instead of broken plates, but this is the term used by the inspectors, and I do not presume to change it.

The report of wheels with cut flanges removed from freight service is interesting as showing, in the first place, in connection with other facts presented, the lighter service, as indicated by the proportion of worn flat and slid flat wheels in comparison with the wheels in passenger service; second, that it is possible that the trucks generally in freight service are not adjusted as perfectly as those in passenger, producing a tendency to run to the flange.

The wheels in freight service represented as broken, may more properly be classed as crooked wheels instead of broken, or at any rate, a large proportion of them, but this is the inspector's definition of the defects.

As to comparative mileage of the wheels removed for the several defects, I am unable to give it; as to wheels in freight service the mileage is difficult to get and is not kept, and the wheels indicated in the report in passenger service had no mileage records kept of their service.

You were correct in believing that the percentage was small of cut flanges.

Letter from F. K. HAIN, General Manager Manhattan Railway.

NEW YORK, April 18th, 1887.

In response to yours of 11th inst.—During the years 1884–85, 350 wheels were removed on account of bad tread and 6 for sharp flange, a proportion of 1 to 58¼.

The average mileage for bad tread is 81 514 miles and for sharp flange 62 082 miles.

Letter from L. C. HIGGINS, Esq., Purchasing Agent of the Lake Shore and Michigan Southern Railway.

CLEVELAND, O., June 6th, 1887.

In response to the first two questions, viz.: "Proportion of wheels removed for sharp Flanges" and "Comparative mileage of wheels removed for sharp flanges and for other causes," I beg to give you the following figures from our records of passenger, locomotive, truck and tender wheels, removed during the year 1886.

Number of wheels removed for sharp flanges....	397	= 12.2	per cent.
" " " other causes.....	2.864	= 87.8	"
Total removed.....	3.261	100	"

Total mileage of wheels removed for sharp flanges.....	21 268 153
" " " other causes.....	162 060 321
Total.....	183 328 474

Average mileage of sharp flanges.....	53 572
" " other causes.....	56 585

I assume the question does not cover freight wheels as the guarantee given upon them is a period of time, and the fact that they are, a large portion of the time, on foreign roads beyond the jurisdiction of the owner, renders it impracticable to keep any accurate record of the service performed or mileage made before removal.

As to the third question, viz.: "Comparative number of sharp flange wheels among steel-tired and cast wheels," I can make no answer, as we have not yet removed any steel-tired wheels or sharp flanges.

To the remaining question, as to the "effect of quality of wheels on the proportion of sharp flanges," we are unable to give any comparison, as all our wheels are made from a mixture specified by ourselves.

Letter from J. N. BARR, Esq., Superintendent Car Department, Chicago, Milwaukee and St. Paul Railway.

WEST MILWAUKEE, WIS., July 4th, 1887.

In my opinion this matter of form of flanges is one of great importance in a pecuniary sense, and one which should be thoroughly and practically investigated. There are so many elements entering into the question, that theoretical investigation is liable to lead to error on account of the difficulty of assigning the proper value to each of the many circumstances that affect the result.

Speaking theoretically, my idea has been that a correspondence between the fillet in the wheel-flange and the head of the rail would be the correct construction if the wheels should slide upon the rail. This is certainly true for sliding pieces; but in the case of rolling pieces it can well be doubted if the reasoning on sliding pieces will apply. In my opinion a close correspondence between the fillet at flange of wheel and the head of the rail would certainly produce a grinding action, which would not only wear the flange and rail unduly, but which would also have an influence on the number of cars which a locomotive could haul.

Looking at the matter in this way, it appears to me that if a form of tread and flange could be designed that would have a tendency to guide the wheel along the track and prevent the flange coming in contact with the rail at all, that improved results might be looked for both as to flange-wear and traction. With this object in view I designed the form of tread and flange shown in the accompanying blue print, dated June 30, 1885. The center of the rail is located on the line marked 10. Toward the outside rim of the wheel the tread, for a distance of $3\frac{3}{16}$ inches, is perfectly cylindrical. Toward the flange the section of the tread increases in diameter for a distance of $\frac{3}{8}$-inch, with a radius of 2 inches. From this point a radius of $1\frac{1}{2}$ inches is used in forming the outline of the tread section, and finally a curve of $\frac{1}{4}$-inch radius extends into the reverse curve of 1-inch radius, which continues to the point of the flange.

It is not possible to say at the present writing whether the proportions given are the best. It may be that the radius used could be still decreased to advantage. It will readily be seen, however, from an inspection of the drawing, that if the rise from the center of the tread to the body of the flange be too much exaggerated, that there will be a tendency to hold the wheel to one point with reference to the rail, and to wear a groove the width of the head of the rail into the tread of the wheel, instead of distributing the wear over the entire surface of the tread. This, of course, would shorten the life of the wheel. Having no data, however, for guidance, it was determined to test the tread in the form shown, and accordingly two chills were made and two wheels were cast in them daily. These wheels were placed in service as made, and a recent review of mileage results is shown in the following statement:

WHEELS WORN OUT.

Defects.	No. of Wheels.	Average Mileage.
Hollow at flange	8	65 471
Hollow from flange	5	83 237
Worn flat	1	60 013
Worn tread	3	78 239
Shelled out	1	12 780
Cracked brackets	4	19 348

WHEELS DRAWN GOOD FOR FURTHER SERVICE.

Defects.	No. of Wheels.	Average Mileage.
Hollow at flange	4	61 738
Hollow from flange	10	57 693
Worn tread	4	72 480

[Worn flanges, none; "hollow at flange" means hollow in tread at flange, not a sharp or worn flange.]

In the matter now under consideration the wheels condemned on account of the defects shelled out and cracked brackets play no part. Investigating the results given above with a view of determining whether the rise from the center of the tread to the body of the flange be too abrupt, it will be observed that there are three wheels condemned on account of worn tread, and that the average mileage, 78 239 is well up to the general average of the worn-out wheels. It may be inferred from this that the rise to the flange is not so great as to confine the wear to a narrow groove in the center of the tread and produce an injurious influence on the mileage.

It should be borne in mind that the failures classified under the head of worn tread, are such that the wear is either at the middle of the tread in a narrow groove or is uniformly distributed over the tread, as distinguished from hollow at flange. The term hollow at flange indicates that the principal amount of wear is close to the flange. The outside of the tread being but little worn, and the flange also being but slightly affected, and the term hollow from flange indicates that the principal amount of wear is on the outside of the tread, that portion of the tread adjacent to the flange being but little worn, and the flange itself being often not worn at all.

The proportion of wheels worn hollow at flange, slight in number, goes to show that there is considerable freedom of play in the wheel across the rail and that the rise or form of fillet at the flange is not so great as to prevent the wheels, under certain circumstances, from breaking and wearing close to the flange. At the same time it should be observed that there is not a single wheel condemned on account of worn flange. I have made it a point to personally inspect these wheels as they were returned from service, and in no case was there a sharp or worn flange, and the general appearance of the tread gave evidence that the flange in sight had but little to do with guiding the wheel on the rail. For purposes of comparison it may be stated that during 1886 ten per cent. of the worn-out wheels arrived from passenger cars were scraped on account of worn flanges, and the average mileage of these wheels was 70 606 miles.

It would not be safe to make any extended deductions from the limited number of wheels with fillet as described, of which record has been obtained, but the results are so encouraging that it has been determined to extend the use of this form of tread and in the course of

about two years we will doubtless have sufficient figures and data to come to a definite conclusion.

I am, however, decidedly of the opinion not only from the mileage figures given, but also from the appearance of these wheels after service, that the best results as to flange wear will be obtained by designing the tread and fillet so as to guide the wheel without bringing the flange into contact with the rail.

With regard to radius of curvature for edge of rail I have not given the matter much attention, and have no data that would throw any light upon this point.

With regard to the effect of quality of wheels on the proportion of sharp flanges, I have not got my data in such shape as to present figures, and it is a matter that could not be very well presented in such a way. The following, however, are my deductions from our wheel records and observations :

First.—It is the exception to find two wheels on the same axle both wheels having worn flanges.

Second.—The conclusion from No. 1 is, that curves have little to do with flange wear.

Third.—The trucks with which I have had experience have little to do with flange wear. This conclusion is arrived at by reversing wheels in the truck when one of the wheels begins to show flange wear, so that the worn flange occupies the position of the good flange and vice versâ. In nearly every case the wheel with the worn flange continues to wear the flange.

Fourth.—If wheels differing in size are mounted on the same axle the small wheel almost invariably wears the flange.

Fifth.—Difference in the wearing quality of two wheels on the same axle is the main, almost exclusive cause of flange wear. The wheel which wears most rapidly being forced against the flange; presupposing of course, fairly good workmanship in trucks and mounting of wheels. If a make of wheels is uniformly poor, there will be less liability to flange wear than if some have very good wearing qualities with the rest poor.

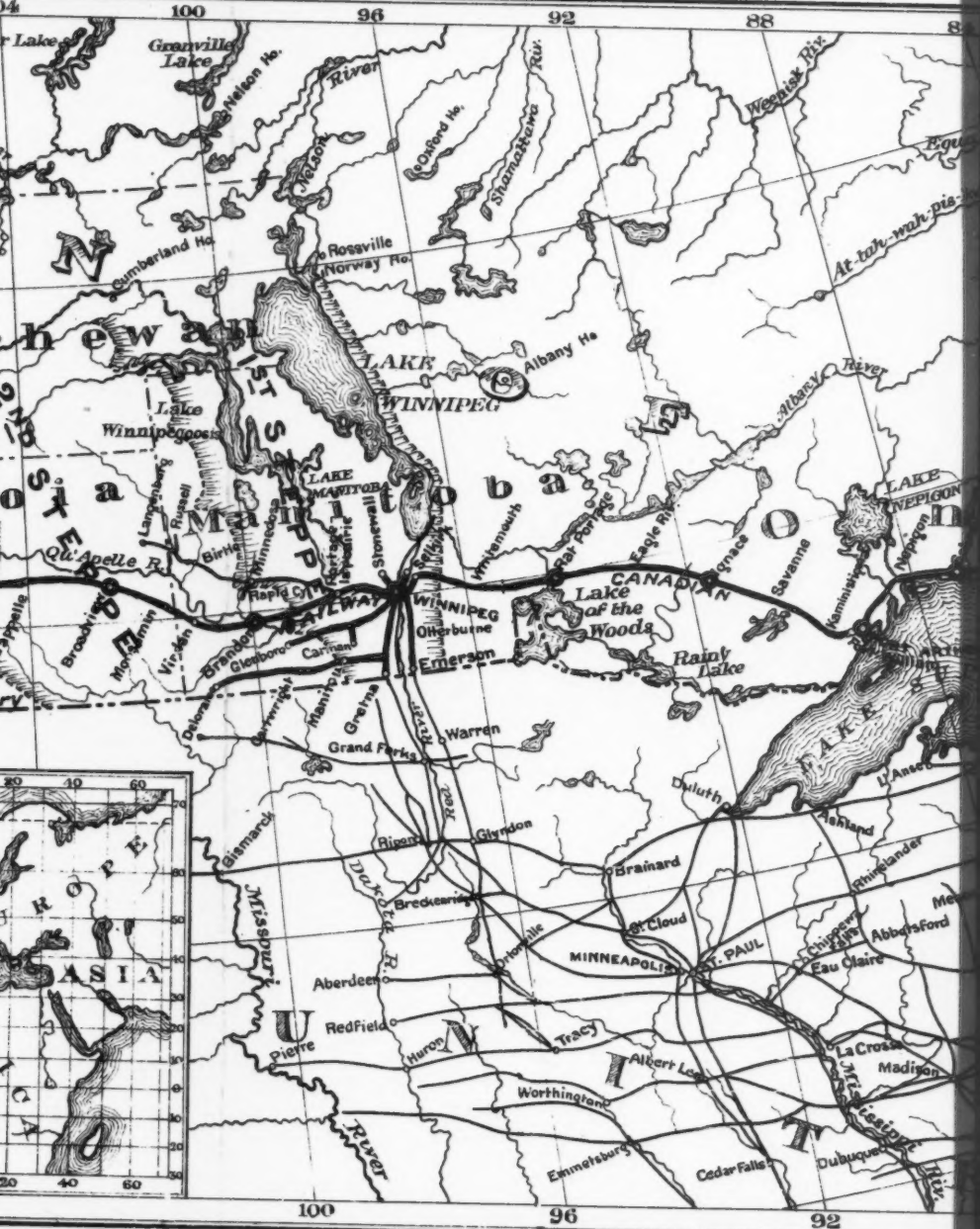
As to the comparative mileage of wheels removed for worn flanges and for other causes, the mileage under passenger equipment of wheels condemned on account of worn flange, is generally a little greater than the average mileage of worn-out wheels (exclusive of sliding) condemned for other defects. This assertion is made from a large amount of data of a definite character which I have not time to present.

As to comparative numbers of sharp flanges among steel-tired and cast wheels it is difficult to make comparisons, as my practice has been to remove and true the wheels up as soon as one give definite signs of wearing the flange, and also to remove such wheels and remate, placing two wheels showing signs of flange wear on the same axle and also mating together those wheels which have preserved their flanges intact. In this way wheels of the same wearing quality are gradually mated together, and the general average mileage increased.

I have now gone briefly over the points referred to in your circular and regret that I have not had time to arrange my figures to re-enforce the positions taken. This is a matter of great general interest, and I would like to obtain copies of what you do in the matter.

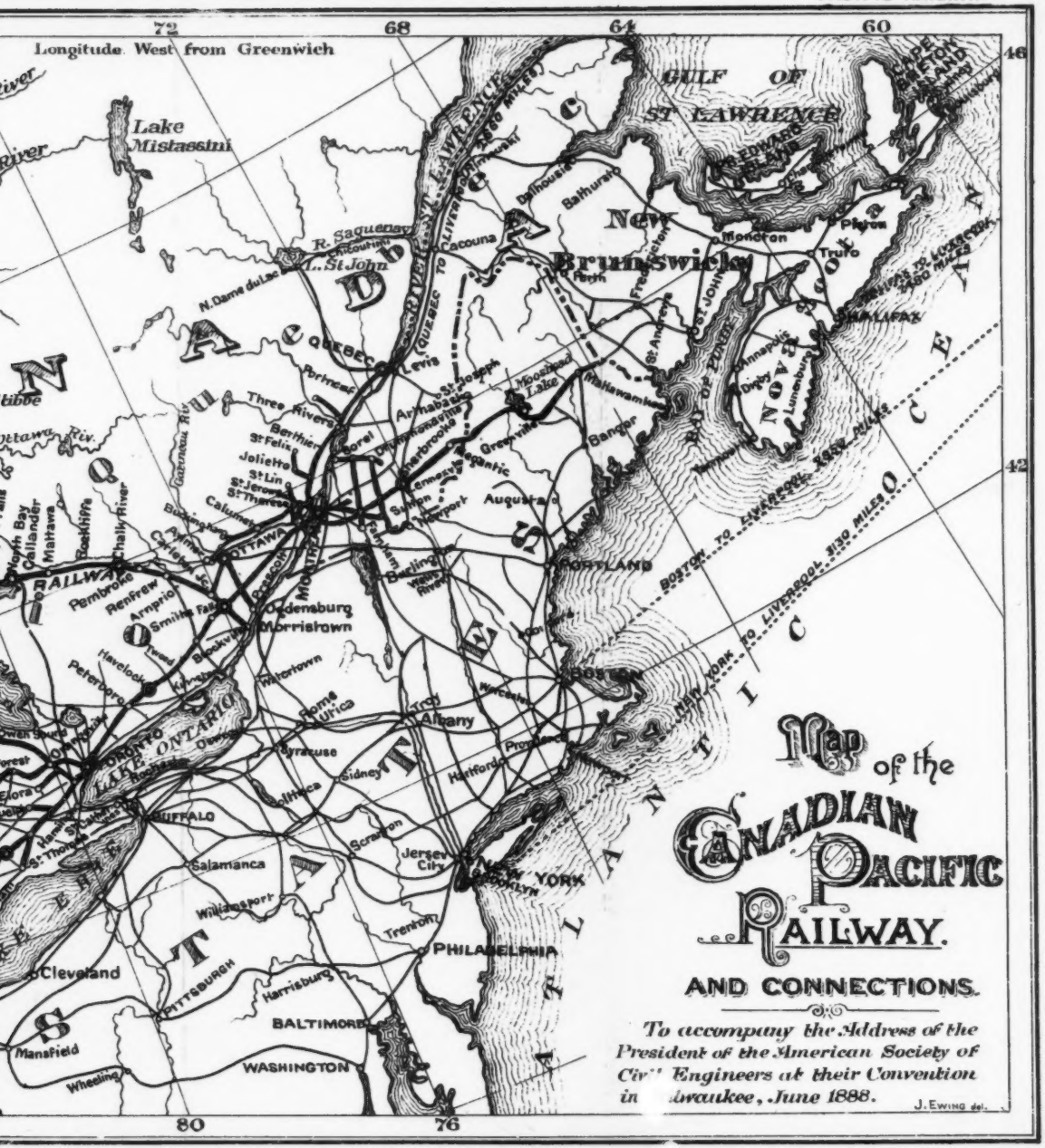
128
124
120
54
50
46
124
Peace River
Ft. McLeod
Skeena R.
Fitzhugh Sd.
Queen Charlotte Is.
Dean Chan.
Bella Coola
Chilco Lake
Quesnelle Lake
Fraser River
Kamloops
Savonas
Ashcroft
Lytton
North Bend
Hope
New Westminster
Nanaimo
Victoria
Vancouver
Vancouver to Nanaimo, Victoria, Seattle
Shagit
Seattle
Olympia
Columbia R.
Portland
Salem
Eugene City
Empire City
Roseburg
Vancouver to San Francisco, Portland & Astoria
Pacific Ocean
Columbia R.
Yellowhead Pass
Jasper House
Athabasca
Rocky Mts.
Golden
Revelstoke
Kootenay L.
Columbia
Arctic Circle
Siberia
Asia
Peking
Shanhai
China
Japan
Calcutta
India
Hong Kong
Pacific Ocean
Australia
80
100
120
140
160
180

116
112
108
104
Athabasca
Little Slave Lake
Athabasca River
Ft McMurray
Reindeer Lake
Churchill River
MANITOBA
Jasper Ho
St Anne
St Albert
Edmonton
North Saskatchewan River
Battleford
Battle R.
Carlton
Prince Albert
Saskatchewan
Alberta
BANFF SPRINGS & NATIONAL PARK
Canmore
Calgary
Gleichen
Bow River
Saskatoon
Assiniboine
2ND STEPPE
Medicine Hat
Cypress Hills
South Saskatchewan
Maple Creek
Sidewood
Moose Jaw
Regina
Qu'Appelle
Chaplin
PACIFIC
Waterton Lakes
Lethbridge
Coal Mines
Belly R.
St Mary R.
Milk R.
International Boundary
180
160
140
120
100
80
60
40
20
0
20
40
ALASKA
NORTH AMERICA
CANADA
UNITED STATES
Honolulu
PACIFIC OCEAN
ATLANTIC OCEAN
EUROPE
AFRICA
EQUATOR
SOUTH AMERICA


100
96
92
88
Granville Lake
Nelson R.
Nelson
River
Le Pas
Le Rossville
Norway Ho.
Cumberland Ho.
Oxford Ho.
Shamattawa R.
Weepisk R.
At-wi-wah-pis-
Albany Ho.
LAKE WINNIPEG
Albany River
Lake Winnipegoosis
LAKE MANITOBA
Manitoba
Saskatchewan
Qu'Apelle R.
Birtle
Minnedosa
Rapid City
Shellmouth
Whitemouth
Eagle R.
Fair Portage
Ignace
Savanne
LAKE WINNIPEGOSIS
CANADIAN PACIFIC RAILWAY
WINNIPEG
Otterburne
Emerson
Lake of the Woods
Rainy Lake
Kaministiquia
Broadview
Moosomin
Virden
Brandon
Glenboro
Carman
Manitou
Greina
Dakota
Warren
Grand Forks
Duluth
L'Anse
Ashland
Rhinelander
Glyndon
Ripley
Brainard
Bismarck
Missouri R.
Bredcenridge
Dakota R.
St. Cloud
Princeville
MINNEAPOLIS
ST. PAUL
Chippewa Falls
Abbotsford
Eau Claire
Aberdeen
Redfield
Pierre
Huron
Tracy
Albert Lea
La Crosse
Madison
Worthington
Mississippi R.
Emmetsburg
Cedar Falls
Dubuque
Missouri River
EUROPE
ASIA
AFRICA

96
92
88
84
80
76
JAMES BAY
East Main River
Rupert's River
Rupert House
Moose Factory
Hurricane River
Equan River
At-tah-wah-pis-kat River
Albany River
Moose River
Lake Abitibbe
Ottawa
Weagisk Riv.
Nelson River
Oxford House
Shamattawa Riv.
Rossville
Norway House
LAKE WINNIPEG
Albany House
Albany River
LAKE MANITOBA
Manitoba
Ontario
Whitemouth
Eagle River
Grace
Savanne
LAKE NIPIGON
Nipigon
Schreiber
Heron Bay
White River
Grassett
Missanabie
Thessalon
Biscotasing
Carrier
Salsbury
Sturgeon Falls
North Bay
Callander
CANADIAN PACIFIC RAILWAY
WINNIPEG
Otterburne
Emerson
Lake of the Woods
Rainy Lake
ARTHUR
LAKE SUPERIOR
Sault Ste. Marie
Soo Mich.
Algoma
Lake Nipissing
Gladstone
Carnduff
Manitou
Gretna
Grand Forks
Warren
Red River
Duluth
L'Anse
Sault Ste Marie
LAKE HURON
Owen Sound
Mt Forest
Elora
Guelph
Bismarck
Rigent
Glyndon
Ashland
Rhinelander
Brainard
Brackenridge
Dakota R.
Missouri R.
St. Cloud
Meponmee
Chippewa Falls
Abbotsford
Eau Claire
MINNEAPOLIS
ST. PAUL
Ortonville
Aberdeen
Redfield
Pierre
Huron
Tracy
Albert Lea
La Crosse
Madison
Worthington
Mississippi R.
Dubuque
Cedar Falls
Emmetsburg
CHICAGO
LAKE MICHIGAN
Manistique
Ludington
Bay City
Grand Rapids
Pt. Huron
Port Huron
Chatham
DETROIT
Windsor
Kalamazoo
Toledo
Ft Wayne
Manistee
100
96
92
88
84

PLATE I
TRANS. AM. SOC. CIV. ENGRS.
VOL. XIX Nº 394.
KEEFER ON CANADIAN
PACIFIC RAILWAY.


Longitude West from Greenwich
72
68
64
60
46
42
80
76
Lake Mistassini
R. Saguenay
L. St John
N. Dame du Lac
GULF OF ST LAWRENCE
Dalhousie
Bathurst
New Brunswick
Moncton
Pictou
Truro
St John
St Andrews
Digby
Lunenburg
HALIFAX
Quebec
Levis
Portneuf
Three Rivers
Berthier
Joliette
St Lin
St Jerome
St Therese
Arthabaska
St Hyacinthe
Sherbrooke
Megantic
Farnham
Granby
Montreal
Lake
Williamstown
Bangor
Augusta
Lewiston
PORTLAND
OTTAWA
Buckingham
Calumet
Pembroke
Renfrew
Arnprior
Smiths Falls
Kingston
Belleville
Cobourg
Port Hope
Oswego
Oxford
Oswego
Oxford
Oswego
Oxford